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Communications should be addressed to the Editor, E. J. McNaughton, B.Sc. (Hons.), B.Sc. (Agric.), Imperial Chemical Industries Limited, Jealott's Hill Research Station, Bracknell, Berkshire, England

FUTURE OF HORMONES IN MEAT PRODUCTION

Less than a year ago it seemed highly probable that the use of synthetic hormones in meat production would forge ahead in Britain. Here was a simple, practical and profitable way of increasing liveweight gains in steers and ram lambs; extensive experiments had accurately defined the doses and times of application that would give the best results; and the fact that three-quarters of all beef steers slaughtered in the U.S.A. had been treated with hormones could be taken as evidence that the technique was acceptable to farmers and, with reasonable precautions, safe to man and livestock. Yet, in the autumn of 1957, reports began to appear of ill effects from treatment, and these have aroused an organized opposition that may jeopardize the future of the technique.

The trouble originated with complaints by Scottish butchers of the poor carcass quality of hormone-treated sheep, and these were soon followed by the widespread expression of fears of potential dangers to milking and breeding animals. The meat trade was quickly in arms, and in Scotland the Institute of Auctioneers and Appraisers took prompt action by recommending that all treated stock should be declared as such on markets, while one consumers' association even went the length of demanding a guarantee of the freedom of hormonized meat from all long-term health hazards. Appeals to administrative authorities for guidance and for control of abuses have received careful consideration, and at various meetings and conferences the views of leading agricultural, medical and veterinary officers and representatives of the trades involved have been fully expressed on hormone treatment and its implications.

Hazards to man are the least of these problems. Oestrogens do not accumulate in the body of the treated animal but are rapidly excreted in the urine and faeces. In the U.S.A., the residue in the edible meat of stilboestrol-fed steers is not more than 1 part in 10 million, which is less than the amounts of natural oestrogens found in vegetables, cereals, milk and other foods. Experiments in the U.S.S.R. have shown that the feeding of stilboestrol to cattle left no oestrogen when treatment was stopped two days before slaughter. Hexoestrol, which is used in Britain, has only one-tenth of the potency of stilboestrol, and the meat of treated animals contains traces so small that a man would have to eat 150 lb. a day before he would receive a therapeutic dose. There is, therefore, no risk to the consumer, and the fact that oestrogens are not destroyed by cooking does not affect the issue. The chief hazard to man is that of absorbing harmful amounts when mixing the substances with feedingstuffs, and farmers can avoid this by buying prepared feed or by having their stock implanted.

Adverse effects on livestock cannot be disposed of so simply. Most of them have arisen through the use of hormones contrary to established principles, but the possibility of harm from the prescribed doses cannot be ruled out and the British Veterinary Association has asked practising veterinary surgeons for details of all instances of harmful effects as a basis for investigation. Some farmers have certainly been overdosing their animals, although it has been proved that any increase above standard levels will not only fail to improve the rate of liveweight gain but lower carcass quality. Animals have also been treated when too young. Worst of all, it is alleged that hormones have been administered, deliberately or inadvertently, to breeding stock and this could lead to infertility and abortion.

A new point that has come under discussion concerns the fate of the residual hormones passing out of the animal on to the soil. These, it is contended, might be absorbed by pasture plants and build up into a serious hazard to grazing animals, particularly to sheep following treated cattle and to heifers and ewe lambs. So far, however, no instance has been recorded of this having occurred. It is not even known whether residual material would persist long enough in the soil to constitute a hazard or be leached out or destroyed by micro-organisms, leaving the pastures safe. In these circumstances discussion is futile. It is facts that are wanted, and steps have already been taken to collect them and to direct research into the aspects that need attention.

Until these investigations have been completed, which may take a long time, the technique will not receive official support in Britain. It may even be discouraged by educative and other measures designed to prevent abuses. Should it be proved, however, that contamination of pastures does occur to a serious extent, the probability is that the use of synthetic hormones may be restricted to implantation, or entirely prohibited as it is in France and Holland.

FACTORS INFLUENCING THE CHOICE OF CEREAL VARIETIES

C. V. Dadd and L. W. Osborne

(*National Agricultural Advisory Service, Eastern Region*)

Cereal yields in Britain have risen by several cwt. per acre in recent years, largely owing to the use of new varieties that resist lodging and respond better than the old to nitrogenous fertilizers. The farmer's problem is to select the right variety for his particular purpose, and surveys show that his choice is influenced to a varying degree by the advisory services and other sources from which he may obtain the information.

The cultivation of cereals in Britain has undergone many changes during the last two decades, of which the most marked has been the recent upward trend in average yields. This has been due in large part to the introduction of new hybrid varieties, and thanks must go to the many plant breeders who have contributed.

The magnitude of the general improvement is shown in Table I. From the abbreviated yield trial data in Table II it will be seen that the yielding ability of some modern hybrids is superior to that of the older varieties. They also respond better to manuring, and this, with the increased use of nitrogenous fertilizers, has been largely responsible for the rise in average yields. But it is not only in yield that progress has been made. Spratt Archer barley, for example, is outyielded by the old Archer barley, yet its other field characters represent a considerable advance for the farmer and, with Plumage Archer, it has quickly replaced the older varieties.

TABLE I

AVERAGE CEREAL YIELDS (CWT./ACRE) IN ENGLAND AND WALES

Period	Wheat	Barley	Oats
1866–1875	14·9	—	—
1876–1885	15·4	—	—
1886–1895	16·2	15·5	10·0
1896–1905	17·5	15·5	10·0
1906–1915	18·0	15·8	10·0
1916–1925	17·7	14·6	13·5
1926–1935	17·9	16·3	15·8
1936–1945	18·7	17·3	16·3
1946–1955	20·8	19·5	18·2
1951–1955	24·1	22·6	20·3
1951	21·7	20·2	18·9
1952	22·6	19·9	19·7
1953	24·0	22·6	21·2
1954	22·6	21·4	19·2
1955	26·7	25·4	22·5
1956	24·7	23·8	19·1
1957*	24·7	21·9	18·0

* Provisional.

The number of named cereal varieties placed on the market has not increased recently—in fact the reverse is the case if the years 1935–9 are compared with 1950–4 for wheat varieties—but the speed of change from one popular variety to another appears to have become greater in post-war years, as is indicated by the numbers of varieties listed for the first time in seedsmen's catalogues in these periods (Table III).

The aim of most farmers in cereal growing, as in farming generally, is to produce a satisfactory profit, and it is generally accepted that a higher crop yield will ensure this in the present economic climate. Farmers have been quick to seize upon new crop varieties, particularly of cereals, as a simple and cheap way of increasing yields and profits. The pressure of advice upon farmers from various sources, including advertising, has reacted speedily upon variety choice, and this aspect is dealt with fully in the second part of this paper.

INFLUENCE OF VARIETAL CHARACTERISTICS ON CHOICE

While tradition certainly plays a part in determining which variety is chosen, it is generally a small part and may often be classed as unwillingness to change. In most areas, especially those where the cereal is for cash sale, the primary consideration is yield-weight of grain safely and easily harvested. To this end lodging resistance is of prime importance, and many farmers are prepared to sacrifice a modicum of yield in favour of strength of straw, should this choice be necessary and straightforward. In many instances today the highest yielding variety is not the strongest in the straw. For example, S147 oats normally outyield

TABLE II

RELATIVE YIELDS OF CEREAL VARIETIES

(Control for each series = 100)

WINTER WHEAT								
Standard Red	100	—	—	—	—	—	—	—
Benefactor	100	—	—	—	—	—	—	—
Squarehead's Master	93	100	100	—	—	—	—	—
Squarehead's Master 13/4	—	—	—	—	—	—	—	86
Yeoman	88	—	—	—	—	—	—	87
Victor	92	—	—	100	—	—	—	—
Wilhelmina	—	109	—	98	—	—	—	—
Setter	—	—	94	—	—	—	—	—
Juliana	—	—	—	102	95	—	—	—
Bersee	—	—	—	—	100	100	100	100
Nord Desprez	—	—	—	—	—	110	108	—
Hybrid 46	—	—	—	—	—	104	107	—
Cappelle Desprez	—	—	—	—	—	—	111	—
References	[21]	[2]	[4]	[5]	[26]	[11]	[8]	[7]
SPRING BARLEY								
Archer	100	—	—					
Goldthorpe	92	—	—					
Standwell	83	—	—					
Scotch Chevalier	91	—	—					
Spratt Archer	92	104	100					
Archer Goldthorpe	—	92	—					
Plumage-Archer (1924)	—	100	—					
Kenia	—	—	100					
Proctor	—	—	116					
Herta	—	—	121					
References	[13]	[3]	[30]					
SPRING OATS								
Abundance	100	100	100	100	—	—	—	—
Potato	83	—	—	—	—	—	—	—
Black Potato	—	—	88	—	—	—	—	—
Black Tartarian	—	—	97	—	—	—	—	—
Victory	99	107	112	—	100	87	87	—
Star	—	—	—	111	—	—	—	—
Eagle	—	—	—	—	—	—	98	—
Sun II	—	—	—	—	114	100	100	—
Blenda	—	—	—	—	—	103	—	—
References	[22]	[23]	[29]	[24]	[17]	[17]	[25]	—

the stiffer strawed S172, and Sun II outyields Milford, yet the lower yielding but stiffer strawed variety is frequently and rightly chosen for fertile land. A few farmers prefer to grow Hybrid 46 wheat rather than Cappelle Desprez because of its slightly stiffer straw and in spite of the slightly higher yield of the latter on mineral soils in the main wheat-growing areas in Britain.

Quality of Grain and Straw

Grain quality and suitability for subsequent use frequently influence choice, especially of barley. Few farmers are still optimistic enough to hope to sell Herta or Rika for malting in England; Proctor or occasionally Earl would be chosen, generally the former, since it can often combine good yield and the quality sought by most maltsters and brewers. It is usually the hope of a favourable price differential for malting which makes barley growers variety conscious. In the absence of financial encouragement, choice among wheat varieties is seldom made on a quality basis, price differences on account of quality usually being small. It may, however, be easier to sell wheat of a certain type or variety, and this can act as the necessary stimulus. Atle (now outclassed for yield) and Svenno are usually good bread wheats, and Minister is a good biscuit wheat; these may even attract a small price premium as well as being easy to sell.

Surprisingly, quality differences operate to a lesser extent in the choice of oat varieties, except perhaps where oats are grown for their straw and cut in the milky stage. For instance, few farmers take careful note of the proportion of husk of a particular variety. Several varieties have achieved popularity because of their nice plump grain shape, and in spite of the fact that the plumpness is due largely to a thick husk (e.g. Onward). Although the kernel percentage varies between the extremes of 78% (Grey Winter) to 69·6% (Onward), that of most varieties is about 75% [14]. At one time the quality of oat straw was of considerable importance; today it is generally looked upon as secondary to yield of grain.

Straw quality in wheat does not appreciably influence many farmers in their choice. Thatchers complain that really good quality straw for roofing is extremely difficult, and in some areas impossible, to obtain in the quantity needed. The popularity of Cappelle Desprez wheat is not lessened by the fact that it is not quite so good for litter as some of the older varieties. It is reported that Cappelle Desprez straw may be unsatisfactory for making mushroom compost, and that it shatters sometimes in the combine harvester and cannot easily be separated from the grain. Cappelle is grown because it is profitable, its main attraction lying in its grain yield and strength of straw.

Field Characters and Disease Resistance

Among the field characters of a variety certain failings may be enough to limit its popularity, however good it might otherwise be. Above all other factors in wheat, liability to sprouting in a wet harvest and lack of resistance to yellow rust have shown themselves of major importance. Susceptibility to yellow rust quickly overcame the rising popularity of Desprez 80 and Nord Desprez some years ago. Liability to sprouting has limited the popularity of Minister wheat; but for this defect Minister might well be classed among the best, and rival Cappelle Desprez in popularity, owing to its high yield, strong straw, vigorous growth, and grain quality generally acceptable for biscuit making.

A variety that sheds at all seriously before combine ripeness is reached is likely to be discarded quickly by farmers; the once popular Bersee was quickly replaced by other varieties after its liability to shattering at harvest had been experienced.

A factor of local importance is the resistance of a variety to manganese deficiency, a trouble only too common on some of the lighter alkaline peat fens. Both Atle and Atson have shown themselves at a great disadvantage on these soils, even though sprayed in the recognized manner with manganese sulphate. The variety Progress and, more recently, Koga II have proved to be greatly superior in practice for these special soil conditions; this is illustrated in the colour plate and by the data from field trials of the Fenland Experiments Committee of the N.A.A.S. shown in Table IV.

TABLE III

WHEAT VARIETIES AND YEAR OF THEIR INTRODUCTION INTO SEEDSMEN'S CATALOGUES

1935
Brooker's Double Standup. Diamond. Extra Kolben II. Holdfast. Hybrid 23. Iron III. Jubilee (Jubilegem). Juliana. Little Tich. Scandia. Squarehead. Sun III. Viking. White Dutch.
1936
Allies. Benefactress. Drott. Drottning. Gold. Golden. Iron. Steel. Wilma. Winter Bearded.
1937
Bacton Masterpiece. Blanka. Desprez 80. Generosity. Imperial Standup. Miracle. Norfolk Squarehead. Robusta. Record. Setter. Standfast Yielder. Vilmorin. 27. Westerfield White. Yeoman D.
1938
Fylgia. Iron Red. King. Menciel. Squarehead the Third. Warden.
1939
Diamond II. Scandia II. Sixty.

1951
Masterpiece. Miana. Minister.
1952
Alpha. Druchamp. Ella. Fylgia. Glasnevin Rosa. Lille Desprez. Pondus.
1953
Alex. Victor II.
1954
Atson. Banco. Heine VII. Howehill. Inversable Bordeaux. Purina.
1955
Aller. Directoire Journée. Dominator. Koga II. Later. Panter. Peko.

TABLE IV

WHEAT YIELDS (cwt./ac.) ON MANGANESE-DEFICIENT SOILS. ATLE COMPARED WITH PROGRESS OR KOGA II (= 100)

	All trials	Fenland (Mn deficient) soils	
		No $MnSO_4$ sprayed	$MnSO_4$ sprayed
Atle	100%	26·2 (78%)	29·4 (87%)
Progress . .	100%	33·6 (100%)	33·8 (100%)
No. of trials . .	60	5	5
Atle	88%	29·7 (64%)	33·6 (74%)
Koga II . .	100%	46·2 (100%)	45·5 (100%)
No. of trials . .	107	3	3

TABLE V

VARIETAL RESISTANCE TO STEM EELWORM IN OATS

(Data from N.A.A.S./N.I.A.B. trials)

Variety	Normal relative yields [25] (%)	Infested	
		Yield (cwt./ac.)	Stems visibly infested (%)
Milford (S225)	87	24·8	0
Opus	100	14·1	51·2
Eagle	98	13·4	57·8
Sun II	100	10·0	71·3
Maldwyn (S221)	99	7·1	66·4

Among the major diseases of cereals, eyespot (*Cercosporella herpotrichoides*) continues to be a common although sometimes unrecognized cause of loss. Recent work by Macer [18] has shown that Cappelle Desprez wheat is more "resistant" to yield loss and eyespot lodging than most other varieties; Minister is partially resistant. This character in a variety is regarded as an additional factor in its favour, but is not likely greatly to raise its popularity if it falls short in such more important respects as yield, straw strength, and resistance to sprouting and to yellow rust. Resistance to mildew may well influence choice when resistant varieties become available, provided they have the other desirable characters, and also that farmers come to recognize the loss in yield from serious mildew attack. An indication of the extent of loss has been given by work at Rothamsted [6].

There are few pests of cereals to which individual varieties show resistance. The most startling case is with stem eelworm of oats (*Ditylenchus dipsacii*). Most varieties are susceptible, but Milford is resistant [15, 19] and despite its relatively low yield is now almost exclusively chosen as the spring oat for land known to be infested with this eelworm. Data in Table V illustrate the point.

Although modern developments are tending to complicate some farming techniques, the demand is for simplicity wherever it can be achieved. The National Institute of Agricultural Botany have met this by streamlining their variety recommendations and now list for general cultivation only three varieties of winter wheat, three of barley, and five of winter and spring oats. A lesser number of each cereal is recognized as of value for special circumstances; others are defined as "outclassed."

Nitrogen and Yield

Without nitrogen the highest yield can seldom be obtained; without the right variety enough nitrogen cannot be applied for fear of lodging. Variety and nitrogen are in fact complementary. Many years ago it was recognized that nitrogen played a leading role in promoting yield, but few dared to apply more than 1 or 1½ cwt./acre of sulphate of ammonia to wheat, for instance. This is no longer so. In all the principal cereal growing areas nitrogen usage has increased, although in some there is still room for improvement. The general situation has recently been summed up by Bullen and Lessells [9], who reviewed a total of 270 trials on the nitrogenous manuring of cereals. Table VI summarizes the yield response of varieties and the average recommended dressings given in that paper.

Referring back to the comparative yield data quoted in Table II, it will be seen that Kenia and Spratt-Archer barleys appear to be of equal yielding ability. This has been shown to be so if both are grown under manuring and fertility conditions normally chosen for Spratt-Archer. Jones [16] has shown that the ability of Kenia to withstand and respond to higher nitrogenous manuring meant that it could be appreciably higher yielding in farming practice—as indeed was quickly realized by farmers. This finding is paralleled with other varieties of barley and wheat, but it has not yet been shown to occur with any of the newer oat varieties. There is evidence from Gardner [12] that certain of the newer French type of wheats will respond to a greater extent to nitrogen than will some older types, but it does not support the presumption that this is due wholly to greater lodging losses in the older weak strawed wheats. Current trials by the N.I.A.B. and N.A.A.S. aim to test the responsiveness of new varieties to nitrogen, and a first report on this work may be expected in several months' time. Meanwhile, it may be said that the data so far examined do not suggest any marked differences between modern varieties in the extent of their nitrogen responsiveness.

Three major problems remain:

(i) To determine whether a particular field will show a response in grain yield to applied fertilizer nitrogen.

(ii) To decide the optimum amount of nitrogenous fertilizer for particular circumstances of field and variety, not overlooking quality considerations with barley.

(iii) To decide when to apply the fertilizer.

Evidence is accumulating regarding the last factor. Current and recent experiments indicate that for spring cereals "all-in-seedbed" is the right technique: withholding some of the nitrogen for later top dressing seldom pays. Research directed by Dr. G. W. Cooke [10] also suggests that there may be general advantage in combine drilling all the nitrogen as well as the phosphate and potash, but this work needs confirming over a wider geographical area before it is likely to be incorporated into general practice. Furthermore, the compound fertilizers now available are not of the correct ratio if the recommended nitrogen dressing for spring cereals is to be combine-drilled; a ratio of 2 : 1 : 1 will be needed before such a technique can be adopted.

TABLE VI

RESPONSE OF AND RECOMMENDED DRESSINGS OF NITROGEN TO CERTAIN VARIETIES [9]

Variety	No. of trials	Grain response to 0·25 cwt. N (cwt./ac.)	Recommended dressing of N (cwt./ac.)	Net return (shillings/ac.)
Winter Wheat				
Hybrid 46	47	4·9	0·69	200
Cappelle Desprez Nord Desprez Bersee Atle	69	4·4	0·65	177
Other varieties	92	3·1	0·51	100
Spring Wheat	51	3·3	0·53	111
*Spring Barley**				
Spratt Archer Plumage Arc	29	3·5	0·50	97
Kenia Herta Freja, Proctor	18	5·8	0·70	207

* No account taken of effect on malting quality: all grain valued at feeding prices.

Most of the winter wheat is grown in the drier parts of England, where lodging is no longer a major problem in normal circumstances. There are indications that the reduced chances of serious lodging is tending to change the long-established concept of withholding nitrogenous top dressings until relatively late in the spring, end April–early May. Trials are showing that it does not seem to matter as much as we thought when spring N is applied, the largest response usually resulting from applications in late March to early April. It does appear clear, however, that the earlier the application of N the larger is the response in straw yield. Thus, the former tradition was based principally on the fear of encouraging lodging.

Exceptions to this pattern exist, for example, on very light land and on land in an extensive ley farming system. Some light land may repay rates of nitrogenous fertilizer higher than on "average" land of medium texture, and, at least on very light land, it may pay to split the dressing between two times of application. On land in an intensive ley system, especially in areas of moderate rainfall, organic matter and nitrogen reserves may be relatively high. In these circumstances the timing and amounts of nitrogen to be applied to cereals need careful consideration. Reduced rates and delayed application to winter wheat may be desirable, e.g. 1½–2 cwt./acre sulphate of ammonia applied in May instead of 3–3½ cwt. earlier. The timing of applications to spring cereals is not likely to be different, but again rates may be reduced.

The responses quoted in Table VI are averages over a number of areas and seasons. It is common knowledge, however, that on occasion nitrogen appears to have little effect on yield, and although season and especially rainfall will influence response this does not supply a full explanation. Analysis of soil samples cannot at present be relied upon to forecast this situation, nor can it indicate the optimum rates for particular circumstances.

Minor errors in choice of application rate seldom have a serious influence on profitability. On moderately responsive land the amount may be misjudged by 1 or even 1½ cwt. sulphate of ammonia per acre and affect profit by only a few shillings per acre; but if, say, 3½ cwt./acre fails to increase yield, the loss in cash is appreciable. This type of problem exercises a number of our soil chemists at the moment, and it is hoped that their investigations will be fruitful and provide the guidance needed in the field.

INFLUENCE OF SOURCES OF INFORMATION ON CHOICE

Although the advantages and disadvantages of varieties in the field may greatly influence the choice that a farmer may make, opinions are not always swayed by logical argument. It may be

TABLE VII

CHANGES IN ACREAGES OF THREE CEREAL VARIETIES IN CAMBRIDGESHIRE, 1955–7

Variety	Year first marketed	Percent. of acreage		
		1955	1956	1957
Cappelle Desprez (Winter Wheat)	1950	31	51	71
Proctor (Barley) . .	1953	34	59	75
Koga II (Spring Wheat) . .	1955	2	30	64

useful then to examine a few of the principles that have been established by psychologists and sociologists on the vitally important subject of communication.

In the report of his investigation on "Innovation and Enterprise in Wheat Farming" among a group of farmers in New South Wales, Parish [20] states that "enterprising behaviour is a psychological response, not a response to the logic of economics and technology." This view is one that has for long been held by scientists in this field of work. The existence of this problem is perhaps not always recognized, but how else can we explain the fact that some individuals do not adopt the best practices until they have been widely accepted and applied on other farms in the neighbourhood? Since the personal whims of the farmer may sometimes be much more important than the soundest economic arguments, the adviser must observe this carefully in attempting to overcome any innate resistance to the acceptance of ideas which would, if adopted, improve farming profit.

Time Lag to Adoption

It is not always easy to reduce the time lag in the acceptance of new ideas, this being partly the result of the farmer's resistance to change. The classical work done by Ryan and Gross [27] on the diffusion of information about the new high yielding maize hybrids in Iowa in the 1930s revealed a distressingly long delay in their adoption by farmers: about 5 years elapsed between the time when farmers first heard of this new type of maize and grew it *for the first time*, and even after ten years only 75% of the maize acreage in Iowa was planted with the hybrid, despite the fact that local advisers and others had adopted a deliberate policy towards encouraging farmers to change from the old to the new.

The Iowa farming community may have been exceptionally conservative, or perhaps the unfavourable economic climate at that time did not encourage new ideas. Whatever the reasons, there is evidence that in Britain the rate of adoption of new varieties is much more rapid.

An excellent example is provided by cereal variety surveys carried out in Cambridgeshire in 1955–7 on some 1000 farms. These revealed (Table VII) that Cappelle Desprez winter wheat, Proctor barley and Koga II spring wheat became the dominant varieties only 6, 3, and 2 years respectively after their introduction.

Compared with Koga II the spread of Cappelle Desprez and Proctor may appear to have been more leisurely, but both had strong competitors under the particular conditions in Cambridgeshire. Before 1953 the variety Nord Desprez outyielded Cappelle Desprez, but then its susceptibility to yellow rust led to a rapid decline in its popularity. At the present time Hybrid 46 is rightly preferred by farmers on fen soils. In the case of Proctor, the competitor was the established variety Earl, which, despite its lower yield, has so far given as good financial returns on the light chalk soils where it has been popular.

Processes of Acceptance

Acceptance of a new idea is not a simple matter, and a number of attempts have been made to describe the various steps in the process. Wilkening [31] recognizes its complexity and suggests that in the course of acceptance a practice is successively heard about, accepted as a good idea, accepted on a trial basis, and adopted completely; but this represents an idealized picture, since one phase shades imperceptibly into the next.

The task of the adviser is further complicated by the probability that the effectiveness of different methods of communication will vary. Thus Wilkening found that first knowledge of a new technique was obtained by farmers from mass media and agricultural agencies such as advisory services rather than from other farmers, yet "other farmers" was quoted more frequently as a source of "most knowledge" than of "first knowledge."

If we apply Wilkening's experience to the acceptance of a cereal variety we would expect the process to go something like the following. First information would be obtained from mass media or an adviser—the conclusion that it was a good idea would probably come from mass media. More details about the variety would come from talking to other farmers who had grown it. Then would follow the stage of trial on a few acres. This experience, coupled with more knowledge from other farmers, would result in adoption of the variety as the main one on the farm. All methods of communication would probably have been of some importance at each stage.

There are, however, complications to be considered. Individual farmers vary in their reaction to information from different sources, and on this point some general principles appear to have been established. Abell [1] suggests that farmers in the top strata react differently from those in the lower strata. In the early stages of his conversion the better farmer is more likely to be influenced by all information media and especially by mass media, though in the phase of actual decision it will be mainly the experts who exert an influence. In contrast, the farmer in the lower strata is mainly influenced by people and by personal information. Here exists a major problem for the adviser, for he is in much less frequent contact with small farmers than with larger farmers, and so has less chance of directly influencing their actions.

Among farmers in the lower strata Abell suggests that there may be an increase in the number of individuals who follow a friendship group leader unreservedly. Some useful guidance has also been given by Wilson and Gallup [32], who found that farmers who hear of a new method from several sources use it more readily than farmers who hear of it from only one.

Advisory Campaign in Cambridgeshire

In the past three years the second author of this article has carried out an intensive programme in Cambridgeshire in an attempt to increase farmers' profits by encouraging the growing of better cereal varieties. In this county the annual value of cereal production is about £5 million. At the beginning of the programme it was calculated that failure to grow the best varieties resulted in a loss of potential income of about £250,000; but by the end of the first two years the improved choice of varieties had increased income by £170,000, spread over a thousand farms.

The Advisory Service in the county employed several methods for disseminating information about these varieties, including press articles, farm walks, advisory visits and lectures, close liaison with corn merchants, a comprehensive series of roadside demonstrations (described by Smith [28]), and the widespread distribution of leaflets on cereal varieties for local conditions. These latter were sent by post to every farmer two or three times each year.

TABLE VIII

PERCENTAGE OF FARMERS INFLUENCED BY DIFFERENT SOURCES OF INFORMATION IN THEIR CHOICE OF WINTER WHEAT VARIETIES

Most important influence	1st Analysis		2nd Analysis	
	Farms over 50 ac.	Farms 10–50 ac.	Farms over 50 ac.	Farms 10–50 ac.
Leaflets	43	29	—	—
Merchant	14	18	28	30
Another farmer	9½	21	18	35
Advisory visit	12	9	24	15
Roadside demonstration	6½	10	—	—
Farm walk	6½	5	13	9
Press article	4	4½	8	7
Lecture	4	3	8	5

Since the beginning of the project in 1955 an annual postal survey of varieties being grown has been carried out in order to assess the results of the advisory campaign. Some 1000 farmers occupying 50 acres or more and cultivating about 94% of the county's cereal acreage were asked to co-operate. In the first two surveys 70–75% of the farmers completed the questionnaire sent to them. In the third year (1957) an additional 600 farmers occupying 10–50 acres were included in the survey, the response being 80% from the larger and 72% from the smaller farmers.

The information so generously supplied by farmers has been used primarily to enable local officers to advise more effectively on the selection of cereal varieties for future seasons. In particular the survey provided data about the popularity of inferior varieties. Opportunity was also taken to determine the relative effectiveness of the different methods of influencing farmers. It was found that in 1955, before the programme had been started, the growers of both small and large acreages of winter wheat chose their varieties rather less wisely than growers of medium-size acreages. By 1957 these differences had been very largely ironed out. Here was some evidence that the pattern of behaviour had changed, but the survey data gave no indications as to the reasons.

An attempt to obtain more information on this point was made in the course of the 1957 survey,

A cereal variety trial in Cambridgeshire on light peat soil, showing manganese deficiency symptoms on Atle while Koga II is resistant.

when farmers were asked to indicate, from a prepared list, which was the most important influence on their choice of winter wheat varieties. The results, compiled from the data returned by 660 farmers, are set out in Table VIII.

Before discussing the results of this survey it should be clearly stated that a postal enquiry of this kind cannot be regarded as a reliable method of ascertaining which sources of information were *in fact* most important, for the answers merely represent the *opinions* of the co-operating farmers. Accurate assessment is possible only by personal case study or by controlled experiment. The first is very time consuming and needs well-trained interviewers; the second is the more promising, and some experience in use is described later.

Perhaps the most significant result is the importance placed by these farmers on the leaflet as an influence in their selection. "Merchant" and "Another Farmer" appear likewise to be strong influences, while advisory visits and farm walks are of lesser importance.

It could be argued from these data that the advisory visit and farm walk are of rather low effectiveness. This is not justified, since there are many more opportunities for farmers to be influenced by leaflets than by advisory visits. Whereas the 1000 farmers of over 50 acres would each have received at least two leaflets on winter wheat varieties, only a few score would have been visited and advised on this subject during the previous couple of years. It may well be, therefore, that in terms of the number of shots fired the target was hit much more often by the advisory visit than by the leaflet, but the leaflet fired very many more shots and so achieved a greater total number of hits.

Comments of the same kind may be made about the figures for other methods of communication which appear to be relatively unsuccessful, such as lectures, articles, farm walks, and roadside demonstrations. They may all suffer from the same weakness—that they do not fire enough shots to make an important contribution to the battle.

In the course of the Cambridgeshire programme a very active publicity campaign was carried out in which the intensive use of leaflets and roadside demonstrations was superimposed on normal methods. Therefore, in order to extract more information from the data (Table VIII, 1st analysis), it may be permissible to re-cast the figures, omitting the response in favour of the "Leaflet" and the "Roadside Demonstration." A further justification for doing so is that for the first year of the programme the distribution of leaflets was not on a comparable basis as between the two farm-size groups. This amended information is set out as 2nd analysis in Table VIII, the percentages being calculated afresh.

The main points of difference between the two farm-size groups are in respect of "Another Farmer" and "Advisory Visit." The influence of "Another Farmer" appears to be greater with the small farmer, and this bears out the view expressed by Abell [1] that occupiers of small farms tend to copy more frequently what other farmers do. On the other hand, they return "Advisory Visit" less frequently than larger farmers.

While the information obtained in this particular inquiry cannot be said to prove anything conclusively, it fits quite well within the principles established in a more precise manner in other countries.

Influence of a Leaflet

A controlled experiment was carried out in Cambridgeshire in 1956–7 in an attempt to measure the influence of a leaflet on the adoption of an improved cereal variety, Cappelle Desprez.

In 1956 the variety Hybrid 46 was popular on a number of farms where Cappelle Desprez would probably have given an extra yield of about 8% and an extra profit of about £4 per acre. Some 150 such farms were chosen for the experiment and divided at random into two equal groups. One group received a copy of a "special" leaflet, while the other group did not. This leaflet explained in simple terms the financial advantages of changing from Hybrid 46 to Cappelle Desprez and was sent out in the late summer of 1956.

During the course of this experiment the farms involved were exposed in full to the various influences acting upon all other farms in the county, including that of the advisory publicity programme outlined above. The special leaflet was therefore in addition to a quite intensive campaign which was already well into its stride by the autumn of 1956. Some farms naturally dropped out for various reasons, and 118 farms were finally included in the experiment. The results were expressed in terms of the acreage of the two varieties.

For both groups of farms Cappelle Desprez in 1956 represented 41% of the combined acreages of the two varieties. By 1957 the proportion of Cappelle Desprez had risen to 65% on farms not receiving the special leaflet—an increase of 24%. On farms receiving the leaflet the proportion of Cappelle Desprez rose to 77%—an increase of 36%. Similar trends were found in all farm-size groups. A preliminary statistical analysis indicates that the increased percentage of Cappelle Desprez on the farms receiving the special leaflet was unlikely to be due to chance. A paper on this investigation will be published in due course.

This experiment, though limited in its scope, indicates that a well-directed mass approach activity can have an important influence on the adoption of a practice of a simple nature, such as the use of an improved cereal variety.

TABLE IX

INFLUENCE OF ADVISORY VISITS ON CHOICE OF WINTER WHEAT VARIETIES, EXPRESSED AS PERCENTAGE OF THE TOTAL ACREAGE OF WINTER WHEAT ON WHICH THE RECOMMENDED VARIETIES WERE GROWN

Cereal year	No. of years on which visited			
	0	1	2	3
1955	42	51	54	56
1957	83	82	85	88

Influence of Advisory Visits

In the evaluation of survey data from Cambridgeshire a direct attempt was made to see if any relationship exists between the number of advisory visits requested by a farmer and his choice of improved varieties.

Table IX compares the choice of "good" winter wheat varieties for the two harvest years 1955 and 1957 by four groups of farmers. For the purpose of the exercise a "good" variety was considered to be one currently being recommended by the N.A.A.S. in the county. The farmers were grouped according to the number of years in a three-year period 1955–7, during which their farms had been visited for advisory purposes by the District Advisory Officer. Choice was expressed by taking the acreage of "good" varieties grown on each farm, first as a percentage of the total winter wheat acreage on that farm, this figure then being averaged within groups. This avoided the bias which would have been introduced if a straightforward acreage comparison had been used. The exercise included 621 farms, the number within each of the four groups varying from 130 to 192.

Looking first at the results for 1955, there is a strong indication of a relationship between choice of variety and visits: on farms not visited the choice was markedly inferior; with increasing use of the services of the District Officer the recommended varieties were grown more frequently. This position prevailed in 1957, but farmers who had not been visited had improved their choice of varieties to a level comparable with that of the farmers visited in one year out of three.

Since 1955 marked the beginning of the intensive N.A.A.S. efforts to encourage the growing of better varieties, it can be assumed that the results for that year represent the normal pattern of behaviour. By 1957, so far as is known, the only new influence at work was the N.A.A.S. programme of mass approach on the subject of varieties, but the evidence is far from conclusive that this has been responsible in part for the changes under discussion.

The information in Table IX is based on visits for all advisory purposes, and few of these would have been concerned with varieties. The exercise cannot be regarded as a valid attempt to measure the effectiveness of the individual advisory visit in influencing choice of varieties.

CONCLUSION

These investigations throw some light on the problems facing advisers in their task of encouraging the adoption of improved farm practices, but many problems remain unresolved. The results suggest that, while continuing to advise the farmer, more knowledge must be sought about the usefulness of other and complementary methods. It seems to the authors that the first need is to define the factors which farmers may regard as of prime importance in connection with any new techniques; these may be technical or managerial, and are likely always to be economic in the long run. The second need is to decide on the best ways of making the farmer aware of the facts, as a first step leading to adoption of the practice. Fundamental research by sociologists abroad has provided most of the basic knowledge which we have on this latter point. The limited evidence discussed in this paper suggests that these principles may apply equally in the present day in Britain.

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CONTROL OF VIRUS SPREAD IN POTATO CROPS

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Nearly all the potato acreage in England and Wales is planted with certified or once-grown seed, for growers believe that stocks cannot be kept more than two years without deteriorating. Post-war experiments have proved, however, that in many areas stock can be maintained for at least four years by spraying to prevent virus spread by aphids, and it is more profitable to do so than to import costly seed in the traditional way.

The area of land under potatoes in the United Kingdom was 796,000 acres in 1956, and nearly one-sixth of this was devoted to growing seed tubers: 78,000 acres in Scotland, 34,000 in Northern Ireland, and 11,000 in England and Wales [7]. Everyone knows that the best potato seed is produced in Scotland and Ireland; indeed, in 1956 all the Irish and 83% of the Scottish seed was in the higher "S.S." or "A" grades, whereas 83% of the English and Welsh seed was in the lower "H" grade. Why should this be so? The answer lies in the extent to which two virus diseases, leaf roll and severe or rugose mosaic (caused by potato virus Y), are spread by aphids in the different areas.

During the eighteenth century growers appreciated that potato seed obtained from the hills of northern England and Scotland was more vigorous than that from the lowlands of the east and south, but not until the 1920s was it generally realized that virus diseases were responsible for such differences, infected plants giving less than half the yield of healthy ones. Until the 1930s English potato crops were riddled with virus diseases, and the healthy seed imported from Scotland or Ireland degenerated very rapidly. Propaganda by the Ministry of Agriculture and seed merchants gradually persuaded most potato growers to buy fresh seed each year or every other year, and this practice, coupled with the ever-tightening regulations of the seed certification schemes, has been so successful that now our potato crops are among the healthiest in Europe. In 1955, 52% of the potato acreage in England and Wales was planted with certified seed tubers newly obtained from Scotland and Ireland, 5% was planted with English or Welsh certified seed, and almost all the remainder with once-grown seed saved from the ware crop. Less than 1% of the seed stocks planted had been grown by the same farmer for more than two years.

Transport of Scottish and Irish seed adds considerably to its cost. In addition, losses from frost and from damage caused by extra handling and subsequent fungal attack are often substantial, and the seed may not arrive early enough to be chitted (sprouted). New seed and its transport amount to about one-third of the total cost of growing potatoes, and twice during recent years scarcity of seed has almost doubled the price. "A" seed averages about £24 per ton including transport, and many growers plant their whole acreage with this every year. Others plant about one-third with new seed and two-thirds with once-grown, which probably costs them about £10 per ton. Thus it is much cheaper to plant home-grown seed, providing it is not virus-infected. Is it possible to grow potato stocks longer on English farms without their degenerating? To answer this question we must consider how the viruses spread and what can be done to control them.

APHIDS AND VIRUS SPREAD

Potato viruses are transmitted by aphids, and the sequence of events varies greatly from year to year and place to place. In Britain the trouble may be said to begin when a few aphids fly in from their overwintering host plants during May and June. The chief species concerned is the peach-potato aphid, *Myzus persicae* (Sulzer), which overwinters in the open on brassicas, sugar beet stecklings, lettuce and other horticultural crops, and weeds, and under shelter in glasshouses, frames and mangold and fodder beet clamps. None of these winter hosts is susceptible to the leaf roll or potato Y viruses as far as we know, so the aphids are not infective when they arrive in the potato crop. Living young are deposited by them in ones and twos here and there, and it is while visiting plants to do so that they feed and spread the viruses from infected plants within the crop. The aphids deposited multiply into a mainly wingless population, the size of which is determined partly by the weather and partly by parasites and predators.

Aphids multiply most rapidly in warm, dry weather. They are attacked by numerous insect enemies, and Hille Ris Lambers [6] has described a complex of over 50 species on potato crops in the Netherlands. When the potato crops begin to mature during late July and early August they become unsuitable for aphids, and mostly winged forms are produced, which fly to other hosts.

A different sequence occurs when many aphids overwinter and a mild spring allows them to multiply on other hosts before potatoes are planted. This has happened in three years since 1941: during 1949, 1950 and 1957. Then numerous winged aphids colonized the potatoes, but predators and parasites had been able to multiply also, and they prevented the development of a large summer population and the consequent flight of aphids during late July.

In the colder climate of northern England and Scotland few aphids overwinter, and crops in the seed-growing areas are not usually colonized until July. The population on potatoes increases slowly, and is often still increasing when the haulms are burnt off [8]. In areas near market gardens, however, and in the absence of as many controlling insects as are found in the south, aphids may become numerous enough to kill potato plants [5].

Numerous experiments in England have shown that at least half of the season's spread of virus can be attributed to the activity of the colonizing aphids in spring [3, 4], and later the winged aphids that are bred on infected plants carry virus to healthy plants in the same crop and in other fields when they leave potatoes in July and August. Not all members of a peach-potato aphid colony will transmit virus, and there are differences in the way they transmit the two viruses. They take some hours to acquire leaf roll virus from an infected plant, and then for at least a day they are non-infective; but having acquired leaf roll virus they remain infective for a long time, often for the remainder of their lives. In contrast, virus Y can be picked up and transmitted within a few minutes, but the aphids lose their infectivity within a few hours when not feeding, and within a few minutes when they feed. They seldom infect more than one plant with virus Y without recourse to another infected plant.

Certified potato stocks usually contain few infected plants, and there is little spread from one crop to another in most areas. There are still a few areas, however, where there is a large acreage of once-grown potatoes, and virus is carried from these into new stocks every year—one is the early potato district of southern Essex, where rugose mosaic is very common. Mosaic is relatively uncommon in the seed-growing areas.

CONTROL BY USING INSECTICIDES

During the last world war attempts to prevent virus spread by roguing (removing the infected plants) and spraying with insecticides failed. Roguing works well in the seed-growing areas, either because it can be done before the aphids arrive or because few plants become infected each year. The older insecticides, such as derris and nicotine, gave an immediate kill of aphids on the crop but had no effect on incoming aphids because they had no lasting action.

With the development of persistent contact and systemic insecticides the position changed. These can be applied before the aphids arrive and remain active for some days. Trials at Rothamsted soon showed that such aphicides as DDT emulsion, parathion or Systox killed incoming aphids before they became infective with leaf roll virus and so completely stopped its spread from infected plants within the crop; they even decreased the spread of virus Y, probably because the aphids were killed before they could make as many flights as unaffected aphids do [1].

In these early experiments we attempted to keep the plants covered with insecticide throughout the growing season, but this involved as many as eight applications at high volume (about 100 gal./acre) with underleaf lances as well as overhead jets on the spray boom. DDT emulsion at 2 lb. of active ingredient per acre per application proved as effective as the other insecticides tested, and was cheaper and safer to handle than most. Later experiments with DDT showed that, in 1955 at least, four or six sprays gave almost as good results as eight when spraying was started as soon as the plants emerged. In 1956 four sprays were as effective as six, and low-volume application (25 gal./acre) was as good as high-volume (80 gal./acre); this was important because few growers have high-volume spraying machines.

Numerous other trials have been carried out during the past few years in different parts of England and Wales, and DDT has been used in most of them, but parathion and Metasystox have been tested in some. Metasystox, which has a systemic action, gives better control of aphids than DDT when applied from above only, but at present there are severe restrictions on the use of systemic insecticides on food crops. The aim in most of these trials was to find out how long stocks could be kept vigorous if sprayed, and sometimes rogued as well. Many have been kept for three, four or more years by spraying five times at fortnightly intervals during the first part of the growing season. The treatments were effective because they prevented all or some of the spread of virus from infected to healthy plants within the same crop. None of them, however, prevented aphids that brought virus from outside the crop from infecting the plants before being killed. Thus spraying was ineffective in areas where much virus was carried from one crop to another, as in the Thames valley and parts of Gloucestershire.

COST OF SAVING HOME-GROWN SEED

Growers will not consider saving their own seed unless the results repay them well for the cost and trouble of spraying, roguing, and storing the seed. The cost of seed produced by different methods has been investigated recently and is described in detail by Broadbent, Burt and Nix [2]. Assuming that "A" certified seed costs £24 per ton including transport, and taking average figures for seed rate, yield, cost of operations, etc., the annual saving per acre of potatoes over a four-year period compared with the cost of buying certified seed every year would be:

1. £5 to £5 10s. if stock seed and once-grown seed are planted in alternate years, i.e. seed to plant the whole ware acreage is saved from the ware crop; or if stock seed is bought for a special seed area every year and most of the produce is used to plant the next year's ware acreage.
2. £6 15s. to £7 if stock seed for the small seed area is bought every four years and kept reasonably healthy either by spraying with insecticide five times or by spraying three times and then roguing.
3. £8 5s. to £8 15s. if seed is saved from about one-third of the ware acreage, which is either sprayed five times or is sprayed three times and rogued, and stock seed is bought for the one-third and "A" seed for the other two-thirds of the acreage every four years.

These figures include the cost of spraying the whole acreage of ware potatoes once, usually in early July, possibly adding the insecticide to an anti-blight spray, to kill the aphids on the plants before they become numerous and fly away, taking virus into the crops from which seed is to be saved. If all growers would prevent the development of large aphid populations on all potato crops containing infected plants, seed stocks could be maintained in England and Wales for many years. That such a co-operative programme is possible has been demonstrated by farmers in the states of Maine and Washington, U.S.A. Some growers in England include an insecticide with the early anti-blight sprays, because they consider that they obtain a larger crop by decreasing damage by insects.

THE FUTURE

Machinery passing through the crop damages the haulms and decreases yield, but at Rothamsted the increased yield from the use of DDT balanced this loss. Nevertheless, it would be advantageous if some treatment could be applied during planting which would keep the plants free from aphids until the diseased plants could be removed. This method is being tested at Rothamsted.

The future, however, lies with the growers and the advisory services. There is no doubt that growers could save considerable sums of money if they wished to do so; but it cannot be stressed too strongly that the work must be done properly. Virus diseases must not be allowed to become prevalent again, which may happen if spraying is inefficient or crop inspections are inadequate. Most growers could easily learn to recognize the symptoms of leaf roll and rugose mosaic, and could then assess the incidence of disease in their stocks. Too many stocks are discarded at present when they are still vigorous, simply because they have been grown for one or two years.

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NEW METHODS FOR STUDYING PLANT DISEASE EPIDEMICS

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New instruments and methods developed at Rothamsted are proving to be of great value in studying the epidemiology of plant diseases. With their aid much has been learned about the infection requirements of potato blight and apple scab, and it has been possible to define more precisely than before when attacks start and how they progress, indicating the direction that further work in control of these diseases by fungicides should take.

It has long been recognized that crop diseases caused by blights, mildews and rots vary in severity from year to year, largely owing to the influence of weather, and that it is usually necessary to start using fungicidal sprays before diseases are widespread. The relation between fungus spread and weather is therefore the basis of most methods of warning of the need and best time to spray. Great progress has been made in the study of this relationship since Van Everdingen [18] said of potato blight: "The experts know well what blight weather is but are unable to define it in terms of standard meteorological measurements"; yet we are still unable to define the precise infection requirement of the spores of most fungi. To succeed in this we need new methods to measure both the activity of parasitic fungi among crops and the weather as it influences their spores. This article describes recent attempts, depending largely on new instruments, to further knowledge of potato blight and apple scab, although the techniques seem applicable to other diseases.

POTATO BLIGHT

Potato blight, caused by the fungus *Phytophthora infestans*, is no longer allowed to cause such losses as led to the Great Famine in Ireland in the mid-nineteenth century, when the diet of the population depended almost entirely on the potato and means of controlling the disease were unknown. The history of those years and of the subsequent battle against blight have been fully described by Salaman [15] and Large [9]. Nevertheless, the struggle is far from over, for the disease still occurs almost annually and has spread the world over, causing serious losses in such new areas as Kenya and the Cameroons.

The disease damages potato crops by killing the foliage and so reducing yield, and by rotting tubers. Ability of the fungus to vary and produce forms able to attack previously resistant varieties has so far annulled the skill of potato breeders in combining resistance with desirable tuber quality. Protective fungicides therefore remain the chief defence, and, to achieve their full effect and to avoid waste, sprays must be applied at critical stages in the development of epidemics. To define these stages it is necessary to know where the attacks start and both how and when the fungus spreads from one susceptible host to another.

Origin of Attacks

With rare exceptions, growers know to within a month when to expect blight in all but dry years, when the disease is of minor importance. Disease outbreak in England and Wales can now be predicted more precisely by experienced plant pathologists interpreting specially collected records of temperature and relative humidity [10, 11]. Despite these advances, the method of forecasting blight outbreaks remains largely empirical, using assumptions, for example of the presence of the fungus, only justified in practice by their frequent fulfilment.

How the potato blight fungus overwinters has long been one of the classic problems of plant pathology. Many fungi survive the period between crops as resistant spores, often the result of sexual fusion. Such oospores of *P. infestans*, very rarely found in Europe, have recently been discovered in quantity in Mexico, where compatible strains of the fungus co-exist; but there is still no evidence that they are important in the United Kingdom. The explanation most generally accepted has been that proposed by De Bary [1]: that the fungus could perennate in diseased tubers and then invade developing sprouts to form lesions and spores above ground.

For long there was little evidence about the frequency and importance of infected tubers in initiating blight in field crops, but recent observations at Rothamsted [6] and in the Netherlands

[17] indicate that attacks do start in this way even though the fungus survives in only a minute proportion of infected tubers. Invaded stems are usually weak and killed when girdled by the fungus, so it is not surprising how rarely they are noticed among the multitude of healthy stems from over 12,000 tubers planted in each acre. Usually the first indication of their presence and influence is the discovery of a small patch, or focus, of plants with many blight lesions before the disease is general in the crop (Figure 5). At this stage it is impossible to be certain that the outbreak originated from an invaded stem and not a stray airborne spore dispersed from a similar source elsewhere. To settle this point the invaded stem must be found before surrounding plants have become infected.

In the last four seasons, to increase the chance of discovery, we planted about equal numbers of healthy and infected tubers in ⅛-acre plots. The foliage of every plant was examined each week, and so the proportion of diseased tubers that produced invaded stems could be ascertained; the observations also showed when the fungus appeared above ground, when it spread to neighbouring plants, and when the resulting focus endangered surrounding crops. In 1955, a very dry year, we found no invaded stems, but in 1954, 1956 and 1957 the first were recorded on 28th May, 12th June and 16th July respectively, and blight was first found elsewhere on 5th August, 1st August and 5th August; between these dates the fungus spread week by week, eventually infecting all plants. At first new infections on foliage (Figure 3) were limited to plants close to those with invaded stems, but later they appeared more often, in ever-increasing number and at greater distances. The period of cryptic spread, between the appearance of the first diseased shoot and the recognition of an epidemic, generally ends with an abrupt change from local to distant infection by the fungus. Ensuring the early appearance of the disease in our experiment did not appreciably hasten outbreaks in the neighbourhood.

It seems probable therefore that sources of the fungus were widely distributed and developed at about the same rate as in our experiments. The results make it possible to estimate how frequent invaded stems are likely to be in crops. Of 3118 diseased tubers planted, invaded stems were produced by 14, 12 (0·66%) being from artificially infected tubers and only 2 (0·17%) from the naturally infected. When stored dry on trays, about half the naturally infected tubers were rejected before planting because they had no live sprout, and from only 20% of artificially infected tubers of six varieties could the fungus be recovered after six months. Survival of diseased tubers in clamps or bulk storage is likely to be even lower. If we assume that all seed stocks contain as much as 1% of tubers which have been infected, that at planting only 1% of these are alive or contain viable fungus, and that 1% of those do succeed in producing an invaded stem, there would be one in about every 100 acres or roughly "one in a million" plants. Even though the rate may vary by a factor of 10 or more times either way, the fact that in most years almost every maincrop potato plant in the country becomes infected is a sufficient tribute to the ability of the fungus to spread.

Protective sprays do little good unless the first is applied before the disease is firmly established, and to avoid waste it is important that applications are carefully timed. To do this it is necessary to know when crops become infected and what causes multiplication of the fungus. There is no doubt that wet weather is required, but some workers claim this is not the only factor. Grainger [2] has argued that changes in the physiology of potato plants play an important part in determining their susceptibility. This view is difficult to reconcile with the ease with which plants of any age can be infected artificially when kept wet for some hours, with attacks in other countries, which may occur soon after emergence, or with the spread week by week that occurred early in the season in our experiments [6]. It is difficult also to imagine any sufficient physiological change happening almost simultaneously in crops of different variety, planted at different dates and manured and managed differently. Nevertheless the proposal merits a critical test. Unfortunately it is not easy to conduct tests in which the possible influence of host physiology is divorced from important environmental factors. Meanwhile it seemed worth defining weather changes which were associated with the appearance of the disease in epidemic proportions.

Weather associated with Disease Outbreak

Previous studies of the effect of weather did not allow the earliest phases of attacks to be predicted accurately or the infection requirements of the fungus in nature to be defined. Instead of measuring the climate above crops it seemed preferable to examine their "ecoclimate," or the environment

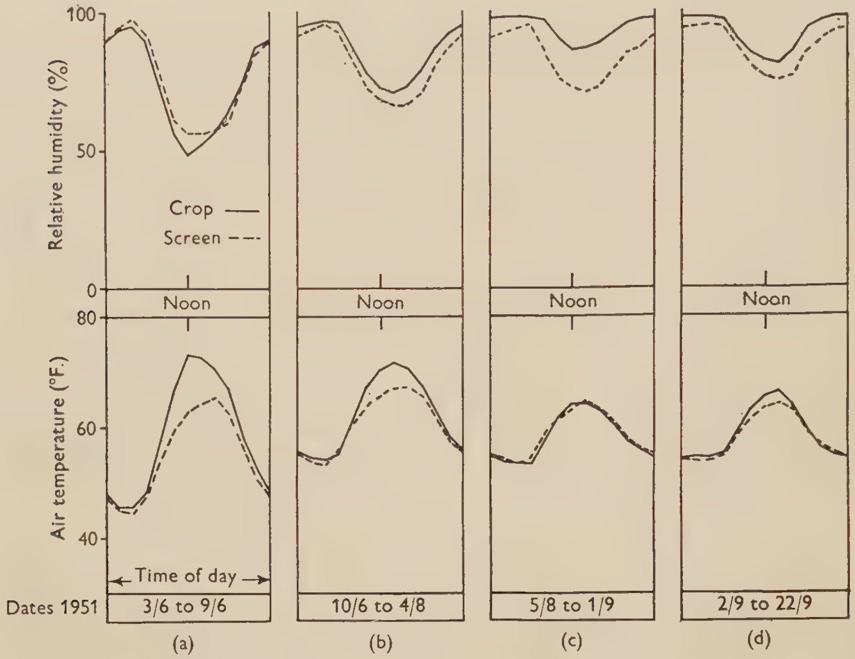

FIG. 1. Diurnal periodicity of air temperature and relative humidity in a louvred screen 4 ft. above ground and between the rows of a potato crop, level with the ridge tops. The growing season of the crop is divided into four phases, described in the text, but separated by: (*a*)–(*b*) the complete emergence of the crop, (*b*)–(*c*) potato blight outbreak, (*c*)–(*d*) destruction of half the foliage.

within the crop. A comparison of the temperatures and relative humidity in standard louvred screens 4 ft. above ground with measurements in the crop, level with the tops of the potato-ridges during six seasons, revealed how the growing crop gradually modifies its environment to one that favours the disease.

The principles are summarized in Figure 1, where four sets of curves show the average diurnal periodicities of temperature and relative humidity in the crop and a louvred screen 4 ft. above ground at Rothamsted during four periods in 1951. The left-hand set, for the week when emergence of plants was completed, shows that air within the crop was both warmer and less humid than above it, particularly around midday. This relationship is typical of warm weather when the soil is dry and sparsely covered by foliage. The second set of curves, from complete emergence to blight outbreak, covers the period during which the growing crop established a full canopy of foliage. The earlier midday differences in temperature gradually decline and the air among the crop becomes continuously more humid than above it. Many features of conditions at the air-soil boundary are transferred to the new "outer-active surface" at the top of the foliage canopy, whereas within the crop there develops a stratum of unusually humid air. After heavy rain, such as occurred early in August, this stratum becomes most pronounced, as shown in the third set of curves representing the relationship between crop and screen from blight outbreaks to the time when half the foliage had been destroyed. The dense foliage intercepts radiation and obstructs ventilation, so that the soil dries very slowly. This relationship has invariably been accompanied by blight epidemics. When much more than half the foliage has been destroyed, soil once again becomes exposed and the fourth set of curves, for the period until the remaining foliage was destroyed, shows

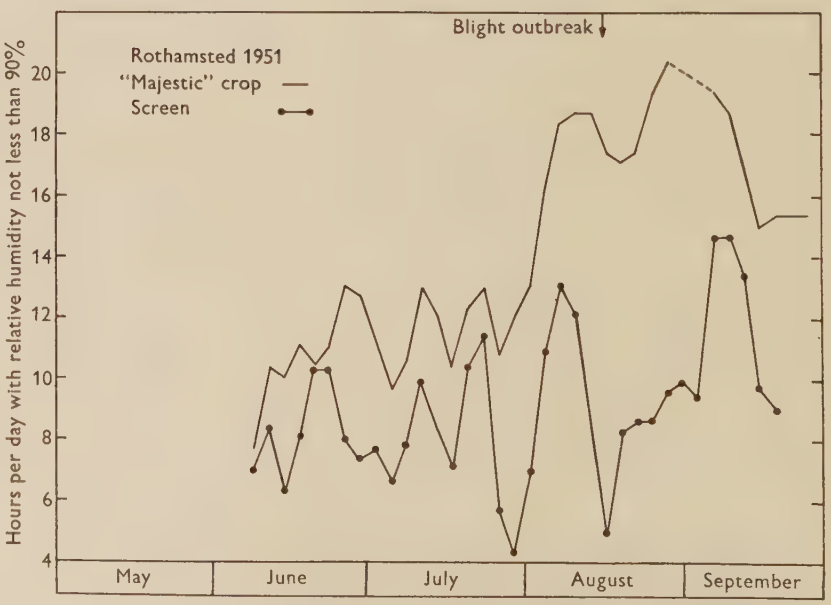

FIG. 2. Running mean curves of hours per day with relative humidity not less than 90% in potato crop and standard screen.

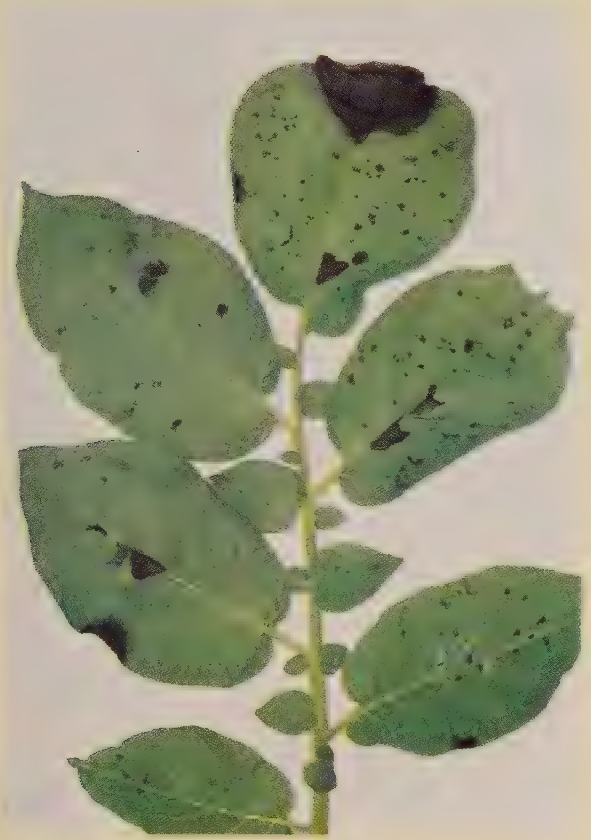

FIG. 3. Potato leaf, showing blight lesions of three different ages. The large, intermediate, and small lesions result from infections which occurred respectively 12, 7, and 4 days before photographing. The small lesions were first visible the day before the photograph.

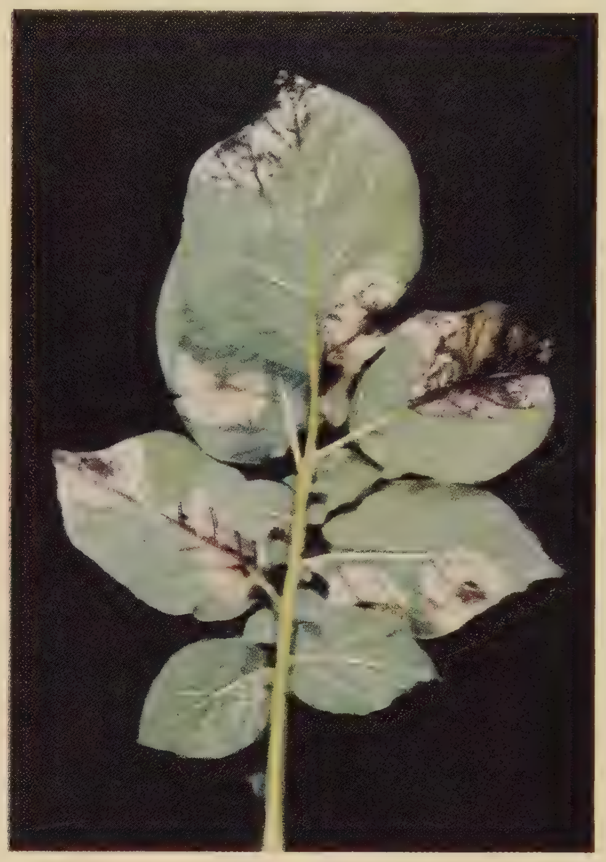

FIG. 4. Underside of potato leaf (Var. Ulster Cromlech), showing white halos of *P. infestans* sporangia produced during an unusually warm, humid night. Note how sporangia are formed on tissues newly invaded by the fungus, not on the central dead parts of the lesions.

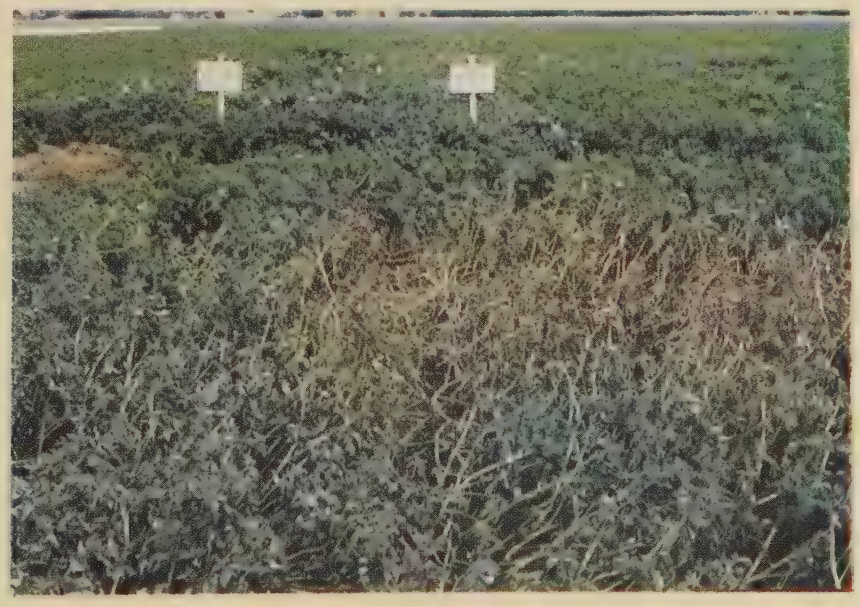

FIG. 5. A focus or patch of potatoes heavily infected with potato blight in advance of the surrounding crop. Variety King Edward at the Experimental Husbandry Farm, Terrington St. Clement, Norfolk, 17th August 1956.

a tendency to revert to the relationship found at the beginning of the season.

The important change in ecoclimate humidity, which regularly coincides with the first widespread infections at increasing distances from the first diseased plants, is clearly shown (Figure 2) by plotting, at three-day intervals, the six-day running mean of the number of hours per day when relative humidity is not less than 90%. Throughout the season in 1951, at screen height, wet spells caused only transient rises in the curve. Early in growth the same happens at crop height; but later, when the foliage is dense and the weather wet, humid conditions persist and favour a prolific production of spores, which is very soon followed by the appearance of the disease in epidemic proportions.

Spread of the Fungus

If this fungus is to prosper, its spores must be transported to new host surfaces where it finds conditions suitable for germination and re-infection. Except for the hazards of the over-wintering phase, re-infection is the most critical stage in the life cycle and the one against which protective fungicides act. We need therefore to understand thoroughly the minute structure and behaviour of the fungus. A crop of spores, or more accurately sporangia of *P. infestans*, can be produced every night when humidity is high. They are colourless, lemon-shaped, about 25 microns long, and are borne on branched stalks which grow out of the leaf through the stomata, so they are more common on the under surfaces of the leaves (Figure 7). After a warm damp night they may become so dense that they show as white haloes marking the night's growth of the fungus around every lesion (Figure 4).

Sporangia are detached very readily in water, and about half the lesions that appeared on healthy plants placed between rows of infected ones seemed to be caused by sporangia carried in water dripping from leaf to leaf. Spores may travel further if they are splashed about in raindrop fragments, but their range is probably limited to a few yards unless the enveloping droplets evaporate before being deposited. The first infections in crops free from sources of the fungus are therefore almost certainly derived from dry airborne spores. To study their dispersal quantitatively a means was needed for catching the minute sporangia from known volumes of air at frequent intervals, both by day and by night.

In 1950 several of the types of spore trap previously used by plant pathologists were tested. All involved the exposure of various sticky surfaces for 24 hours. None fulfilled the need, because of the long exposure, variable efficiency and inability to provide quantitative estimates of spore concentration. The design of a trap [3] better suited to our purpose followed closely the principles used in the "Cascade Impactor" [12]. Air is drawn at 10 l./min. through an orifice of 2 × 14 mm. in cross section (arrowed in Figure 11), behind which is an adhesive surface on a microscope slide on which spores and other particles are deposited. Spores caught at different times are fractionated by moving the slide upwards continuously at 2 mm./hr. A day's catch is accommodated on about 2 in. of a microscope slide. By counting the spores on traverses of

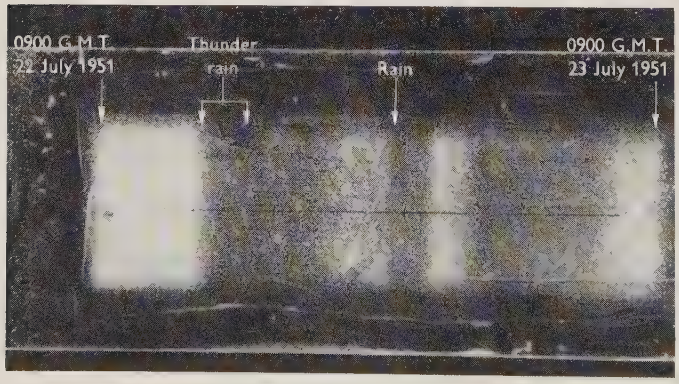

FIG. 6. Exposed but unmounted slide removed from trap at 0900 G.M.T. on 23rd July 1951. Illuminated with beam of light almost parallel to slide so that dense deposits of spores and other particles reflecting light appear as white areas.

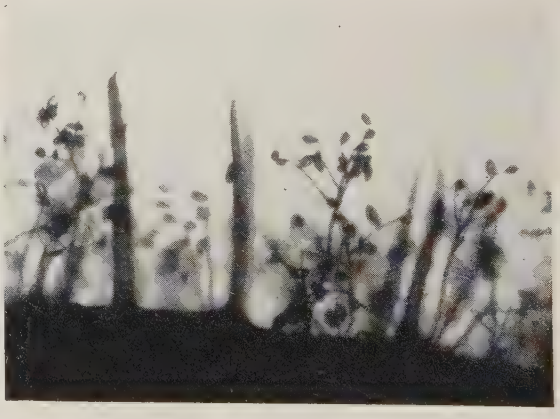

FIG. 7. *P. infestans* sporing on under-surface of a potato leaf. The rigid hairs on the leaf are approximately ½ mm. high.

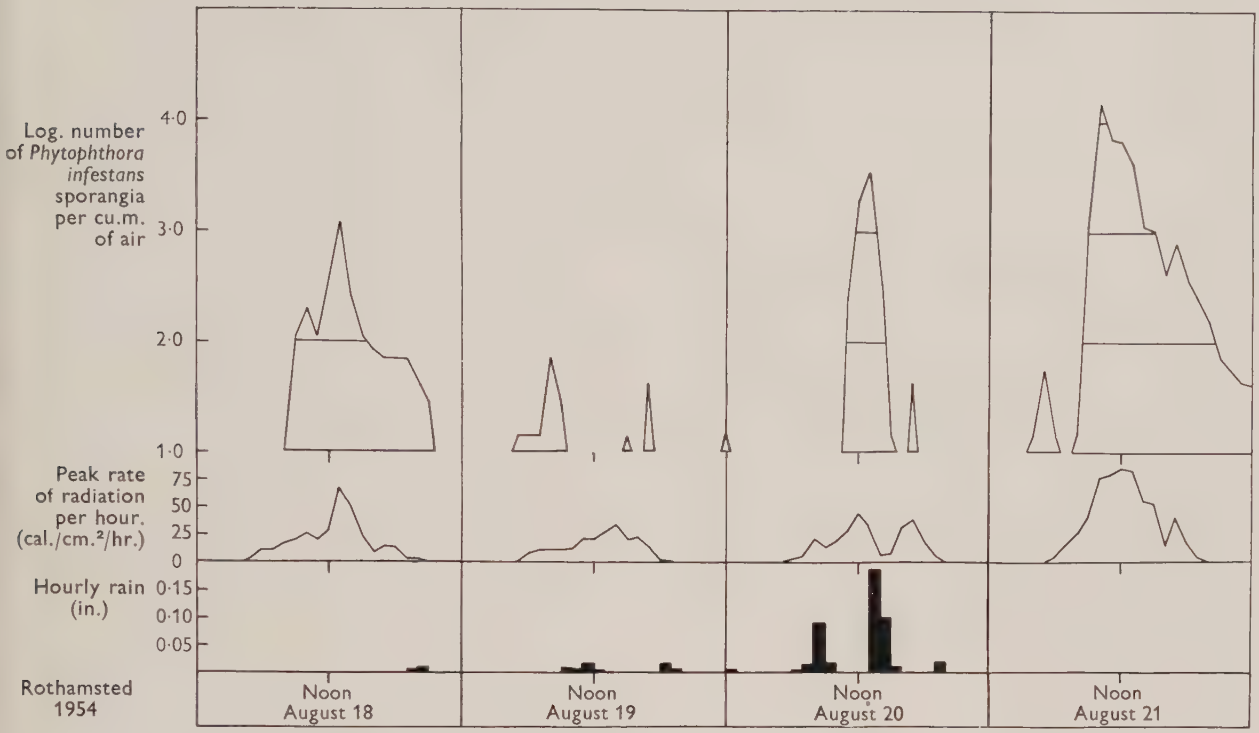

FIG. 8. Atmospheric concentrations of *P. infestans* sporangia measured ½ m. above ground level in an infected crop, illustrating how concentration varied with rain and radiation during four days. Typical behaviour is for liberation to start at 0700, to reach a peak at about 1100 and then to decline, so that few are found after 1900 G.M.T.

known width across the slide at regular intervals their concentration may be estimated hourly.

Density of the deposit varies considerably hour by hour. On the slide photographed in Figure 6, the solid matter suspended in the air was twice decreased by rain. Microscopical examination showed that rain removes some types of spore from the air but that these are replaced by different types [4]. Abrupt changes like this may be completed within an hour or two, but spore concentration is always changing and the frequency of many types shows a diurnal rhythm. *P. infestans*, for example, is usually most common in the forenoon, which incidentally was not at all what had been expected. If weather influences liberation a forenoon maximum suggests that the sporangia, known to be formed chiefly at night, cannot be air-dispersed effectively until the following morning when rising temperature and falling humidity produce drying conditions. The rhythm can apparently be modified by rain (Figure 8), which decreases numbers in the air at the time, or by bright sunshine (high rates of radiation), which increases them at least during the early part of the day before supplies are exhausted. When, on dry days,

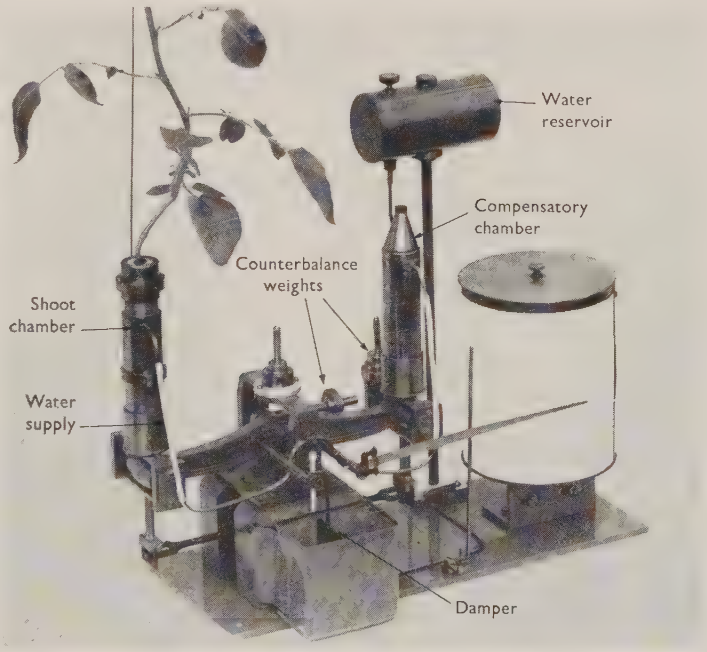

FIG. 9. Dew-balance removed from protective housing. Water supply pipes are flexible where painted white.

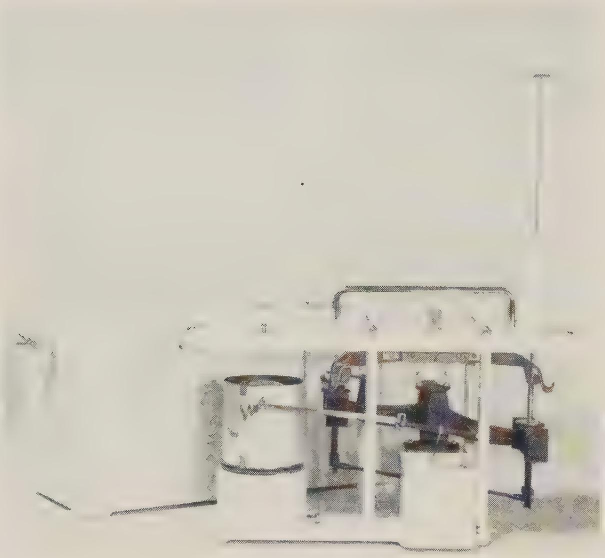

FIG. 10. Surface-wetness recorder with the box in which it is housed. The instrument is placed on a stand so that the test surface is about 6 ft. above ground level.

hourly spore concentrations are compared with corresponding values of single weather factors, they are found to be most closely correlated with radiation, and particularly with its peak rate during the hour.

This suggests that spore liberation may result from some active process and not, as hitherto sometimes suggested, by passive dislodgement. We have therefore observed the process in a very small wind tunnel, along which variously conditioned air-streams can be passed at different speeds. Sporangia are not removed by wet or dry "gales," such as they would be unlikely to experience in crops. The only ways, other than wetting, to cause liberation are by very rapid changes in relative humidity or by strong light. As humidity changes act over a wide range of wind speeds and both in the light and dark, whereas radiation works in almost still air but not when it is quickly moving, it seems probable that rapid local changes in humidity are the operative mechanism and that these changes are sometimes generated very close to leaf surfaces by radiation.

When the potato blight sporangium has been deposited on its host it is entirely dependent on water for survival and further development. Germination is chiefly by the production of about 8 minute zoospores; these swim actively for a time in leaf water droplets, then settle and form cell walls, and finally each produces a germ tube which penetrates directly through the surface of its host. Some of the zoospores may complete these complex processes within two hours of deposition if the temperature is optimal; temperature and length of time the leaf surfaces remain wet determine the proportion that will eventually infect. Measurement of ambient temperature presents little difficulty, but there was no method for recording the length of time leaves were wet.

Conditions for Infection

It is understandable that meteorologists, engaged chiefly in aviation forecasts, have not been interested in measuring the wetness of surfaces; even had they been, a living leaf would have been about the last test surface they would have chosen. To interpret how fungus spores would act on living leaves there seemed to be little alternative to using these surfaces, at least until the extent of errors from the use of inert surfaces had been assessed.

Having decided to attempt this by weighing, continuously, the external water deposits on living shoots, it was helpful to find that over 10 g. of water are retained by a moderate-size potato shoot when sprayed to "run-off". Thus there was no need for delicate balances, unsuited to use in the open. The chief problem with a plant growing in a pot was to avoid the changes in weight caused by rain falling on the soil, drainage, evaporation and transpiration. These changes were not only uncontrollable but unwanted and large compared

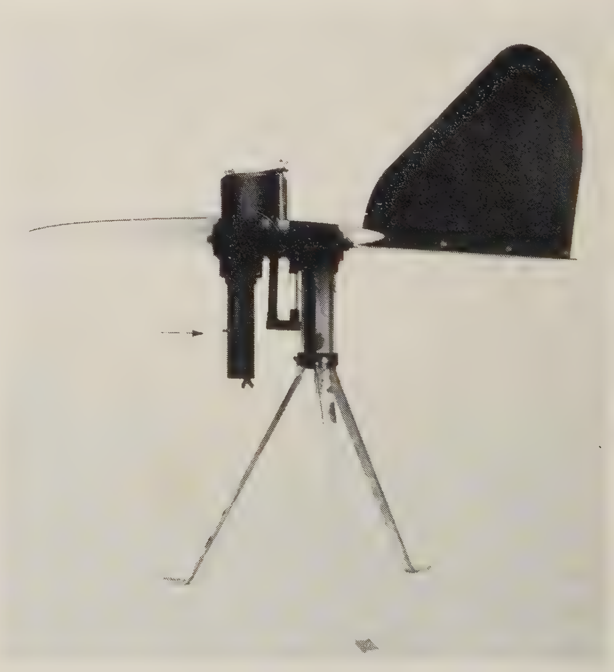

FIG. 11. Hirst spore trap, made by Casella Ltd., London. Arrow denotes sampling orifice on cylinder covering runway for microscope slide.

with variations in weight due to external water deposits on shoots.

By sealing a cut shoot into a water-filled chamber placed on one arm of a balance [5] (Figure 9) it was possible to eliminate such complications as rain falling on soil and drainage or evaporation from it. Transpiration was allowed for by providing a reservoir, not supported on the beam, but linked with the shoot chamber by small-bore pipes, parts of which were flexible. The shoot could then transpire freely without altering the equilibrium of the balance, although such movement was not impeded by the flexible water-supply pipes. It proved necessary to place another water-filled chamber of equal volume on the right-hand side of the beam; it too had a water supply connecting it with the reservoir, but no shoot. This compensator chamber was merely to counterbalance changes in equilibrium resulting from change in volume of the water in the shoot chamber at different temperatures. Provided the shoot does not wilt, and except for rapid oscillations produced by wind, equilibrium alters only because of changes in external water.

After short experience it was easy to tell from records made on the rotating drum when shoots were wet or dry and whether the water was deposited as dew or rain—even whether the rain took the form of drizzle, shower or heavy downpour. The balances were designed primarily to measure how long surfaces were wet, because it is not possible to distinguish from climate records whether leaves remain wet for two or for twelve hours, and there is rarely any indication of dew.

The useful life of individual shoots on the balance varies; potato shoots usually last about a week, those of woody plants rather longer. The succession of shoots makes it difficult to estimate amounts of moisture per unit of leaf area. Neither can the balance record how deposits are distributed on different parts of shoots or individual leaves; this is an important disadvantage in dealing with blight in potato crops, for the dense canopy maintains a more humid atmosphere near the ground, and water deposits from even brief showers may be retained long enough for the lower leaves to become infected while the upper leaves escape. This probably explains why the disease is usually found first on shaded lower leaves and appears preferentially in places like leaf axils or margins where large water drops collect and persist. For these reasons it has not proved easy to predict infection from records of the wetness of shoots.

These difficulties are not so pronounced with other diseases, and records of surface wetness have so far been used more successfully with apple scab because the fungus grows slower and the susceptible parts are well away from the ground.

APPLE SCAB

Apple scab became increasingly troublesome in the large Fenland fruit-growing area centred on Wisbech soon after the war. There were probably several aggravating factors, and it is now unlikely that their relative importance will ever be known. The orchards, mostly planted with Bramley's Seedling early in the century, lie on fertile reclaimed land. The variety was then regarded as resistant to scab, and it seems probable that its present susceptibility is due to the development of a new and more pathogenic strain of the fungus. Despite careful attention to methods of application and the timing then recommended, even 12 or more applications of lime sulphur failed to control the disease.

Although apple scab may reduce yield, freedom from blemishes is far more important because it determines the value of the crop and whether it is worth storing to await high prices. For this reason the aim of control must be to give absolute protection of the fruit, and this is difficult to achieve. The apple scab fungus, *Venturia inaequalis*, may infect most young parts of apple trees. It may overwinter on twigs or bud-scales of some varieties, where from early spring onward it produces asexual spores called conidia. These can infect fruits and foliage to produce further conidia. Alternatively, the first infections may be caused by the sexually produced ascospores. These are formed in spherical fruit bodies called perithecia, which occur buried among the tissue of dead apple leaves and mature in spring, just before the apple buds burst. Within each perithecium are numerous asci, sack-like structures, each containing 8 spores, which are ejected when the leaf is wetted and dispersed by air currents.

Spore Dispersal

In 1953 Dr. I. F. Storey of the National Agricultural Advisory Service asked for help from Rothamsted in the hope that our new spore traps might be used to resolve long-standing arguments about the relative importance of these two types of spore and about the date of first infections. In the five seasons 1953–57 we made 14 series of estimates of spore concentration. The results of 13 of these were analysed, and in none of the five orchards were any overwintering conidial infections found on twigs or buds. If the first infections in spring were caused by conidia it seems reasonable, therefore, to assume they were not produced in the orchard and dispersed locally by rain but must have been introduced by air from a distance. Our spore traps would not detect waterborne conidia, but traps operated among heavily scab-infected trees in summer caught large numbers of spores on both wet and dry days. Only once were conidia detected in an orchard before scab was found on newly formed leaves. In contrast, we found ascospores in every series, at times over three or four thousand per cubic metre of air. In our experience it seems that ascospores are a much more important source of infection than conidia [8] and they infected soon after bud-burst in some years before the date of the first spray recommended, so that the disease was allowed to establish itself unchallenged on the highly susceptible tips of leaves and sepals then exposed. The resulting lesions would be producing multitudes of conidia within a few weeks, and it would then scarcely be possible to control the disease.

Control of Infection by Fungicides

It is vital to prevent the early infections but not at all easy to time and apply protective fungicides so that they continuously and completely prevent infection of the rapidly unfolding buds and expanding leaves. In fact it would be quite uneconomic to spray frequently enough, and much of the control achieved probably depends on redistribution of fungicides in surface water films. The susceptible area exposed by the tree is probably at a maximum between green cluster and petal-fall, for then every leaf of the spurs is highly susceptible. Later, when these spur leaves have become resistant to infection, the fungus readily attacks only the expanding fruits or the 3–5 top leaves and buds of extending shoots. On rapidly growing shoots about two new leaves may be unrolled each week, so there is a quick turnover of tissues susceptible to infection. Assuming, perhaps boldly, that a fresh leaf is produced every four days and only four are susceptible at any one time, the susceptible area of the tree would be replaced every 16 days, and 62 or 88 per cent of the highly susceptible leaves would be unprotected if sprays were spaced at intervals of 10 or 14 days.

This seems to be a strong reason for examining carefully whether it is practical to use fungicides having a curative action, which can be applied after infection has happened and would cover the whole leaf area exposed to infection. Some spray materials, notably the phenyl mercury compounds, can kill the fungus soon after it infects leaves. Unfortunately they are phytotoxic to many varieties of apple. Bramley's Seedling, however, is rarely injured, and so provides a good subject for testing curative sprays.

Timing of Curative Sprays

Since ascospores are liberated more frequently than conditions allow them to infect their hosts, it would be wasteful to spray after every spore liberation. On the other hand, to delay spraying until lesions become visible would be equally unsuitable, for the shortest incubation period (about 7 days at 73° F) is nearly twice as long as the period after infection for which phenyl mercury sprays have a curative action (about 4 days).

The need for some method to detect days when infection occurs is obvious, and the most promising seemed to be to define the infection requirements of the fungus meteorologically. This problem has been studied by Mills [13], who, after more than 15 years of tests, published tables showing the period of continuous wetting at various temperatures which led to apple scab infection in New York State. Mills and Laplante [14] used their method to decide whether to apply elemental sulphur to support a primarily protective spray programme, when infection was threatened and protective deposits were incomplete. Elemental sulphur sprays kill germinating spores immediately, but the deposits do not persist long on leaves. To avoid waste, therefore, sprays were withheld until spores, released by rain, had begun to germinate. Only when it seemed inevitable, from inspection and weather prospects, that the leaf surfaces would remain wet long enough at the prevailing temperature for infections to become established was the decision made to spray.

Mills's purpose differed from our need in the important particular that the grower had to be present to decide the need to spray, and to do the spraying immediately. So exacting a method seems unlikely ever to be used successfully in the U.K., but his information relating temperature and duration of leaf wetness to infection is by far the most detailed and warranted careful testing. His results also impressed other workers, notably in the Netherlands, where extensive trials were soon in progress. These trials and observations at Wisbech both suggested that a method for indicating the need to spray could be developed.

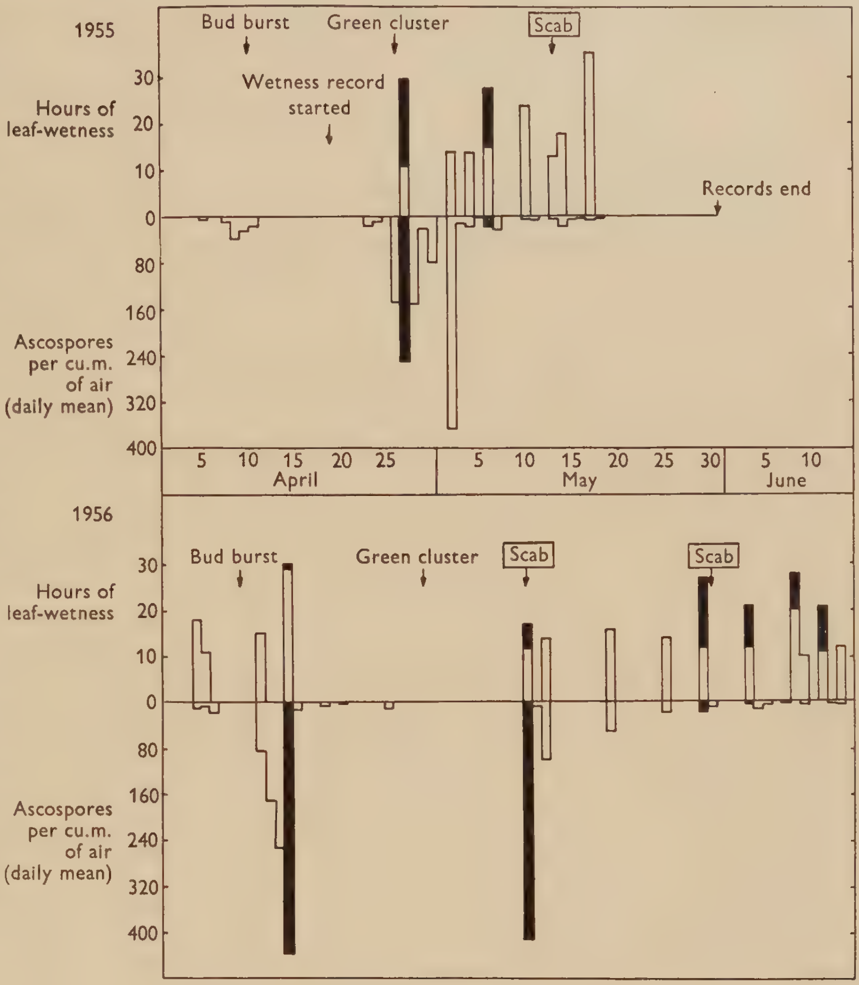

FIG. 12. Probable occurrence of apple scab infection periods at Wisbech. Black erect columns represent opportunity for infection; black pendant columns represent accompanying ascospore inoculum.

Accordingly at Wisbech, in 1955, in addition to spore traps, a recording rain gauge and thermograph, we installed a balance for measuring the duration of leaf wetness. The results stressed the importance of the time at which rain fell. For example, the water deposit from 1 mm. falling at 6 a.m. might last only 3 or 4 hours, so that the released and germinated spores would be killed by drying before they could infect, whereas an equal amount of rain at 6 p.m. would usually keep the leaves wet for at least 12 hours, or long enough to permit successful infection. The instrument was not well suited to routine use, because shoots had to be periodically changed and spring frosts caused burst pipes in the water supply. These difficulties could be eliminated if a non-living test surface could be used without introducing unacceptable errors. With the help of the Meteorological Office a simplified surface-wetness recorder was made, using as test surface a block of expanded polystyrene, sandpapered smooth [7] (Figure 10). Tests showed that this indicated the same period of wetness as did living apple shoots, except during the earliest stages of dew formation, and this recorder was used in 1957 instead of an earlier model.

By interpreting records of spore concentration, leaf wetness and temperature, in accordance with Mills's proposals, both the date and the approximate severity of infection can be estimated. Figure 12 displays the relevant information for different orchards at Wisbech in 1955 and 1956. Erect histogram columns show all occasions when the leaves were wet for more than 9 hours, which is, according to Mills, the minimum required for infection at any temperature. Wetness persisting longer than the minimum required at the temperature prevailing is shown in black; the height of the black portions of erect columns represents the opportunity for infection—the taller they are the higher the proportion of spores likely to infect. Corresponding pendant columns are shown in black to emphasize the proportion of the total liberation accompanying infection weather and also the relative number of ascospores released during different infection spells.

In 1955 ascospores were liberated on 26 days, but the liberation was accompanied by weather suitable for infection on only 2 days. Of these, 27–28th April appeared outstanding, for many spores coincided with ample opportunity for infection. Growers in the district were warned and advised to apply curative sprays at once. The discovery of the first scab lesions on 12th May agreed well with infection at the end of April, and Storey and Ives [16], who surveyed many orchards at the end of May, found a significant correlation between the percentage of spurs with infected leaves and increasing delay in applying curative sprays after 27th April. No evidence was found of infection having occurred on 6th May, but little was expected because there were few ascospores and only a brief opportunity for infection. On 16–17th May leaves were continuously wet for 36 hours, but the temperature at Wisbech was so low that more than 48 hours was required to establish infection and no new lesions were found or expected. Infection periods were exceptionally scarce in 1955, so the year provided an unusually clear demonstration of the importance of accurate spray timing for both efficiency and economy. Infection was possible more often in 1956, but most occasions were brief or occurred late in the ascospore release period, when few spores remained. Many new scab lesions were found in the district on 10th and 30th May as a result of infections on 12–14th April and 9–10th May respectively, although as in 1955 they were few or lacking in orchards where curative sprays had been timed according to the records from instruments. Experience shows that even with this help we cannot yet be fully confident in predicting infection dates and that we need further knowledge of how the fungus behaves during brief dry periods within infection weather.

It is not easy to assess whether any useful advance has been made from the collection and interpretation of such records. Analyses of spray programmes and surveys of scab infection on fruit at picking in orchards in the Wisbech area leave no doubt that growers have used organic mercurial spray materials increasingly and suffered less and less from scab in the years since 1952. Those to whom seeing is believing may be tempted to claim they are connected as cause and effect; but caution is well advised because over optimistic pronouncements could easily do a serious disservice both to growers and to plant pathology. The observations were intended to reveal what type of, how many, and when spores of *Venturia inaequalis* were in the air of orchards. They were expanded later because of the urgent need for guidance on the timing of curative sprays. They must not be expected to prove whether the changes observed resulted from improved control treatments or from weather less favourable to the fungus. Ever since this work started there have been long dry spells in spring, and none of the years since 1954 has been characterized by heavy attacks of scab; such weather has not subjected the method to a rigorous test. The doubts might be resolved by subsequent wet springs, but reliance on such slow methods seems unwise, particularly as some features do suggest an effect of treatment.

In the air of one orchard at Wisbech we have now recorded ascospore concentrations for five consecutive years. By totalling the hourly estimates of the number of spores per cubic metre of air we obtain numbers representing the relative ascospore dose each season. In thousands, these totals have been consecutively 21, 24, 30, 1·5 and 0·5 from 1953 to 1957. Thus in the last two years ascospore dose has averaged only 4% of that in the previous three. The big drop in 1956 followed a dry year which happened also to be the first in which sprays were timed accurately. In a second orchard a similar decrease (40 to 2·7 thousand) followed the same change in control measures but applied in 1956 instead of 1955.

It seems probable that these questions will only be solved by detailed quantitative examination of the extent and ascospore productivity of dead leaf in orchards that have received different treatments, and we are now engaged in this work. The methods described cure neither potato blight nor apple scab, but they have taught us a good deal about both and, more important, pointed the direction which further work on control should take.

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THE RÔLE OF TOXINS IN PLANT DISEASE

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Interest in the rôle of toxins in plant disease was sharply aroused by the claim, made in 1941, that the symptoms of a disease had been alleviated by "antidoting" toxins formed by the pathogen. Although this has not been proved, it is now known that several toxins do produce some of the symptoms of certain diseases. But other mechanisms are involved, and toxin-inactivation seems unlikely to become a practical method of disease control.

Plant diseases caused by parasitic fungi or bacteria are usually detected in the field by the appearance of characteristic symptoms, that is by some fairly obvious changes in the infected plant or plant-organ. These may take such forms as wilting, destruction and discoloration of tissues, dwarfing, or local hypertrophy, and their effects are usually manifest to the farmer in reduced crop yields. Actual macroscopic evidence of the presence of a parasite may only appear much later than the first symptoms, and sometimes not at all. In other words, the concept of parasitic disease is associated with infections causing symptoms of reduced vigour or abnormal and economically useless growth.

Infection, however, is not necessarily associated with damage to the host; it may even be beneficial, as when the roots of certain plants are infected with nitrogen-fixing bacteria or mycorrhiza. Thus, the mere presence of another organism within the tissues of a plant is not enough to cause disease, and we recognize an infection as pathogenic only when the host suffers by the association. This raises a problem of some importance: how does infection in some cases cause destruction or disorganization of host tissues?

It is possible to envisage a number of destructive mechanisms:

(*a*) The sheer mass of parasitic cells accumulating in host tissues may have undesirable mechanical effects, e.g. interference with conduction of water and solutes from root to shoot.

(*b*) The parasite depends on the host for supply of preformed organic compounds and may deprive the host of materials for cell growth.

(*c*) Enzymes secreted by the parasite, even though they may be similar to enzymes produced by the host, may cause widespread destruction of host tissues or tissue components.

(*d*) Metabolic products of the parasite diffusing to host tissues may have toxic effects.

Any of these could produce disease symptoms in host tissues not immediately invaded by the parasite and eventually cause death of the host. Probably all play a part in causing the symptoms of any one disease, but in this article the significance of the toxin mechanism will be more particularly examined.

THE TOXIN THEORY OF DISEASE

The idea that disease is caused by infection with specific micro-organisms was firmly established in plant pathology long before it was generally accepted by medical men [21]. The work of Prevost on bunt of wheat and of Berkeley on potato blight, in which the significance of fungal infection was clearly demonstrated, preceded by many years the work of Pasteur, Koch and Lister, with whose names the germ theory of disease is most often associated. But in the century that followed Koch's work on anthrax far more money has been spent on animal and human pathology than on plant pathology, and far more workers have been attracted to the medical field. Consequently, the material background of symptom development has been less deeply investigated for plant diseases, and the thinking of plant pathologists has for long been coloured by discoveries made in medical science, particularly in relation to toxin theories of disease. This tendency is not intrinsically bad, for there are many analogies between diseases of plants and animals, but an uncritical introduction of concepts from the one field of study to the other can lead to serious errors.

It is worth devoting a little space to the development of toxin theories of disease in medical pathology. The most significant early work was that of Roux, a pupil of Pasteur, on diphtheria. He showed that infection in this disease was highly localized, yet severe haemorrhage and inflammation occurred in organs distant from the seat of infection. He also showed that cultures of the diphtheria bacillus contained a toxic substance which, if injected into animals, would reproduce some of the symptoms of infection. Further, by giving a series of sub-lethal doses of the toxin, he was able to induce in animals resistance not only to the toxin but also to infection by the living bacillus.

We now know that many bacteria pathogenic to man and animals produce toxins, and that most of these toxins are proteins. Moreover, they are antigenic, so that specific antitoxins can be made which will selectively neutralize corresponding toxins. This has placed a powerful weapon in the hands of pathologists, because by use of these antitoxins they can detect specific toxins in animal tissues and prevent the harmful effects of toxins; such diseases as tetanus have been reduced to risks of little importance by the development of immunization techniques. Thus, there is unequivocal evidence that symptoms of many bacterial diseases of man and animals are caused by the production of toxic proteins in the host tissues, though, as van Heyningen [27] has stated, a critical attitude to toxin theories is still necessary.

Similarly many plant pathogens produce disease symptoms distant from the infection, and many also produce phytotoxic materials in culture, some of which at least will reproduce in plants some symptoms of diseases caused by the toxin-producing organism. Influenced no doubt by the striking successes of the toxin-theory of disease as applied to animal pathology, some plant pathologists have concluded from such observations alone that certain plant disease symptoms are produced by the toxins which they have discovered in culture. However, as Dimond and Waggoner [12] have very usefully pointed out, such conclusions are at worst fallacious, at best doubtful, unless presence of the toxin in infected host tissues is proved. Unfortunately proof is more difficult in plant diseases than in animal diseases, for the toxic materials produced by plant pathogens are not antigens, so that serological methods of detecting them specifically are not available. Nevertheless, there are strong indications that some plant disease symptoms have a toxigenic origin [5], and this is best approached by considering critically a few distinct kinds of plant disease.

WILT DISEASES

The wilt diseases of herbaceous plants, commonly caused by fungi of the genera *Fusarium* and *Verticillium* and by some bacteria, are essentially vascular diseases. The infective agent first establishes itself in cortical tissues of root or stem and thence invades the vascular system. Characteristic early symptoms are wilting of leaves and eventually of petioles and stems, and brown discoloration of the vascular bundles. These are usually succeeded by stunted growth and possibly by death of the plant.

The earliest investigators usually attributed wilt symptoms to plugging of the xylem with bacterial cells or fungal hyphae, so that the plant shoots were denied water and succumbed to desiccation. This view was taken by Smith [26] in his studies of wilts caused by *Fusarium vasinfectum*. Later workers were not convinced that this mechanical explanation was adequate, pointing out that (*a*) the observed degree of vessel blocking was less than sufficient to account for the wilt, since direct experiment showed that partial blocking had little effect on water transport, and that (*b*) such symptoms as vascular browning and accumulation of gummy materials, which appear well in advance of the invading pathogen, could not be explained simply by vessel blocking. Further, in some instances, as with the *Verticillium* wilt of tomatoes investigated by Bewley [1], cut shoots placed in cell-free culture filtrates developed charateristic symptoms of wilt and vascular browning. Bewley was able to fractionate culture filtrates to some extent, producing a crude material, probably protein, which would reproduce many symptoms of the disease if introduced into cut shoots. He concluded that the invading fungus secreted an enzyme which travelled up the xylem in the sap stream, either having a direct toxic action or, by lytic effects on host tissues, liberating gummy or mucilaginous substances that occluded the vessels and caused wilt. His view, very similar to those of some recent workers, was that wilt was caused partly by toxic metabolites of the fungus, partly by mechanical blocking.

Thereafter, despite the critical attitude taken by Brown [9], toxigenic theories of wilting became more popular. Indeed, very strong evidence in favour of this view was produced by Gottlieb [16], who showed that centrifugates from the vessels of tomatoes infected with *Fusarium lycopersici* would cause wilting and vascular browning if introduced into healthy plants. This result encouraged further work on the toxins produced by *F. lycopersici* in culture, the work of the Zürich school, led by Professor E. Gäumann, being outstanding. This group isolated two pure phytotoxic substances from cultures of *F. lycopersici*—lycomarasmin and fusaric acid [13–15]. These are fairly simple substances structurally, lycomarasmin being a dipeptide and fusaric acid a pyridine carboxylic acid. Both cause wilting if introduced into cut shoots, and both produce discoloured lesions in some stem and leaf tissues, of a kind sometimes seen in tomato wilt. Exhaustive studies were made of the mode of phytotoxic action of these substances, and it appeared that, in spite of their chemical dissimilarity, both caused water loss by a similar mechanism. A characteristic effect was to increase water loss and water uptake, water loss eventually overtaking uptake, so that wilting resulted; but this wilting was in general irreversible, whereas physiological wilting resulting from excessive transpiration is usually partially reversible.

Though it was never explicitly claimed that wilt symptoms were entirely due to production of these toxins in host tissues, the work of the Zürich school was frequently interpreted in that way, and consequently has been subjected to a considerable amount of criticism. In the first place, it is fairly clear that neither of these toxins will reproduce all the symptoms of tomato wilt—vascular browning, for instance. Secondly, physiological studies have produced little evidence of excessive transpiration as more than a minor characteristic of the water economy of wilted plants, nor of increased permeability of leaf mesophyll cells, which Gäumann and his colleagues had shown to be induced by treatment with pure toxins. Accordingly, it now seems that toxin production in tomato wilt may be of secondary importance; but it should be noted that whereas *in vivo* production of lycomarasmin has never been demonstrated, the presence of fusaric acid in wilt-infected plants has been unequivocally proved [19, 20]. Though this line of investigation appears to have reached an impasse, other methods of approach have led to developments of a different kind.

Ludwig [23], reinvestigating the water economy of the wilt-infected plants mentioned above, found no evidence of excessive transpiration but definite evidence that the water-conducting power of the stem was reduced. This was confirmed shortly afterwards by other workers. He also demonstrated—and it is astonishing that this had never been observed before—that many vessels were plugged, not with fungal hyphae, but with hyaline pectic material. It has now been found that heat-labile materials are present in culture filtrates of *F. lycopersici*, which will cause the formation of such vascular plugs and vascular browning. These are probably enzymes; but, though pectic enzymes and polyphenoloxidases have been implicated, the nature of the reactions that precede browning and plugging are still obscure [11]. This, in a sense, is a return to the views expressed by Bewley in 1922.

Tomato wilt and many other wilt diseases of similar character do not seem to be explicable entirely in terms of toxin production. The intervention of heat-stable toxins is still not certain, but is possible, and reactions induced by secretion of extracellular enzymes by the pathogen seem likely to be of greater importance.

LEAF-SPOT DISEASES

Under this heading are included diseases characterized by small local lesions on leaves and to some extent on stems; in severe attacks the lesions may coalesce to form extensive necrotic and discoloured areas. In several such diseases, three of which are discussed below, toxin production has been implicated.

Blight of Oats

In the early 1940s a number of varieties of oats of common ancestry, bred in the United States for resistance to crown rust (*Puccinia coronata*), developed a previously unrecognized disease caused by infection with *Helminthosporium victoriae*. The fungus appeared to be a weak pathogen, causing rather localized basal rotting. A red striping of the leaves, starting in lower leaves but eventually reaching those borne higher on the stem, usually followed infection. No fungus could ever be isolated from discoloured leaves, which suggested that the striping was toxigenically produced. It was later shown that fungal culture filtrates contained toxic material which would cause leaf discoloration. This did not prove that a toxin was produced *in vivo*, but the discovery that extracts of leaves of infected seedlings were highly phytotoxic, whereas extracts of those of healthy seedlings were at most only slightly phytotoxic, and that varieties of oats resistant to the disease were also resistant to the toxin produced in cultures, made it almost certain that toxin production is involved in the natural disease. The toxin has now been isolated: it is probably a polypeptide, and is of remarkably high toxicity [22, 25].

Tobacco Wildfire

In this bacterial disease, caused by *Pseudomonas tabaci*, numerous small angular spots are produced in infected leaves, each spot being surrounded by a broad yellow halo. Bacteria can be found abundantly in the necrotic spots but are absent from the chlorotic haloes. Cell-free culture filtrates, if injected into leaves, will also cause chlorotic haloes. These observations suggested intervention of a toxin, and this view was supported by the observation that attenuated strains of the bacterium, which had lost the power to produce the toxin in culture, also lost the power to produce haloes when inoculated into leaves, though necrotic infection spots were formed normally. The toxin has been isolated and shown to be α-ϵ-diamino-β-hydroxypimelic acid. Its toxic effects are apparantly due to interference with methionine metabolism in the leaf. Though it has never been isolated from leaf tissues it seems almost certain, in view of the specificity of the symptoms, that it is produced there by the invading organisms [2, 28].

Early Blight of Tomatoes and Potatoes

The causal fungus, *Alternaria solani*, infects leaves, stems and fruits. Infections are commonly localized in dark necrotic spots from which the fungus can usually be isolated, but there are circumstances when lesions appear to be free of fungus. In young plants where the first infections are on the stem, sterile lesions sometimes appear on leaves formed above the primary infection, and in more mature plants infections of petioles sometimes result in the production of sterile lesions on the leaves. This has been interpreted as evidence that such lesions were caused by translocated toxins [24].

Support for this view came from quite unrelated investigations. In the search for antibiotics with antifungal properties it was found that *Alternaria solani* produced such a substance. This antibiotic, alternaric acid, is a dibasic acid of molecular formula $C_{21}H_{20}O_8$; it has the remarkable property of severely restricting extension of fungal germ-tubes without actually preventing germination, so that a reasonably specific bioassay could be developed. It seemed that this substance might be the toxin believed to be produced by *A. solani* when it invades tomato or potato plants, and simple tests showed that it was indeed highly phytotoxic. It caused black papery lesions very similar to those seen in diseases caused by *A. solani*, and these were produced in intercostal areas of leaf or stem, and not in the veins, as in the natural disease. Moreover, juice expressed from infected tomato fruits contained substances that inhibited fungal germ-tube growth in the same way as alternaric acid. It thus seemed highly probable that production of alternaric acid was responsible for some of the symptoms of alternaric blight. Unfortunately for this hypothesis, some highly virulent strains of *A. solani* were found to be incapable of producing alternaric acid in culture. This situation thus remains obscure, though it is not impossible that other toxins related to alternaric acid may also be involved [7, 10, 24].

DISEASES INVOLVING HYPERTROPHY

So far we have considered diseases where infection results, whether by secretion of toxins or not, in sub-optimal nutrition or necrotic changes in host tissues. But the most obvious symptoms of some plant diseases are due to excessive multiplication or extension of host cells, resulting in such structures as galls or witches' brooms. Proliferation and extension of plant cells are known to be regulated by special hormones—the auxins—of which 3-indolylacetic acid is the best known. Consequently, attempts at biochemical explanation of gall-formation have often taken the form of demonstrating that the infecting organism can produce indolylacetic acid in culture, from which it has been deduced that production of this substance by the parasite in host tissues is responsible for the symptoms.

There are several pitfalls in this argument. In the first place, many fungi will produce indolylacetic acid if grown on substrates containing tryptophane, as they would if growing in plant tissues, yet few cause tissue proliferation when they infect plants. Secondly, plants are able to destroy any excess of indolylacetic acid unless it is a very great excess. Thirdly, close investigation of some diseases involving hypertrophy has shown that the symptoms cannot be explained by any such simple hypothesis. This is best illustrated by reference to a few examples.

Maize Smut

In some smut diseases, though not in those commonly found in cereals in Great Britain, large swellings develop on infected plants as a result of host-cell proliferation. The maize smut, caused by *Ustilago maydis*, is an excellent example, in which galls are produced on leaves, stems and inflorescences. The gall tissues contain more free indolylacetic acid than normal tissues. Application of excess indolylacetic acid to wounded tissues causes cell proliferations somewhat reminiscent of gall tissues in morphology. Wolf [29] showed that *U. maydis* will produce indolylacetic acid in culture, if provided with tryptophane as a precursor, and he contrasted this behaviour with that of another smut fungus, *U. nigra*, which is unable to produce indolylacetic acid in culture and causes no tissue proliferation when it infects barley plants. He suggested that production of indolylacetic acid by the fungus in host tissues was mainly responsible for gall-formation. This explanation is plausible, and may be correct; but the evidence is entirely circumstantial. Many other plant diseases are known where infection leads to tissue proliferation or cell extension which might well be attributed to auxin-excess and where a similar explanation of symptom development has been given [6]. The next two examples illustrate the dangers of this kind of reasoning when unsupported by direct evidence.

Crown-gall Disease

In galls caused by infection with *Bacterium tumefaciens* there is again a higher concentration of indolylacetic acid than in normal tissues, and the pathogen, like the maize smut, will produce indolylacetic acid *in vitro*. Further, certain attenuated strains, incapable of producing indolylacetic acid in culture, appear to have become non-pathogenic. Thus crown-gall might well be considered to arise as a consequence of production of indolylacetic acid by the parasite in host tissues, and this explanation was at one time proposed; but such a simple explanation is now known to be wrong.

Three lines of evidence against this view are particularly strong. (*a*) The attenuated strains mentioned above will successfully infect plants if a little auxin is added to the inoculum. Auxin alone induces no proliferation, nor will the attenuated bacteria alone initiate infection. (*b*) Infected plants may develop secondary tumours distant from the original infection, and these secondary growths may be completely bacteria-free. The bacteria initiate a change which becomes self-perpetuating, not dependent on their presence. (*c*) Tissue culture study of crown-gall cells has shown that tumour cells are unlike normal tissue cells in being completely self-sufficient for several growth factors, including auxins. Thus the high auxin levels characteristic of tumour tissues are derived from changed host cells, not from the parasite. The rôle of the parasite appears to be to initiate, by means not yet understood, a decisive metabolic change in the host cells, which become synthetically more self-sufficient. Auxin-production by the parasite is of significance, at most, only in the early stages of establishing an infection [3, 4].

Bakanae Disease of Rice

This disease is caused by *Gibberella fujikuroi*, a soil-borne fungus common in warm countries. Infected rice seedlings grow taller than healthy ones, both stems and leaves being longer. This effect is due to increased cell-length, and might well be considered to be a typical response to auxins. *G. fujikuroi* will produce indolylacetic acid in culture if supplied with tryptophane. Nevertheless, many years' careful investigation of this disease has shown beyond doubt that the increased growth is due, not to auxin production, but to secretion by the fungus of growth-promoting substances—the gibberellins—physiologically and chemically quite distinct from the auxins [8].

These three examples serve to show that abnormal growth reactions of plants after infection with pathogens cannot safely be attributed to auxin production by the parasite without careful investigation yielding direct evidence. On the other hand, in the last example at least, the abnormal growth has been shown to be due to a specific metabolic product of the parasite, which in this context may be considered to be a toxin.

DISCUSSION

No attempt has been made in this paper to array all the evidence that some symptoms of plant disease are toxin-induced. The intention has been, by discussion of a series of examples, to give some idea of the kind of evidence that is available, and to illustrate the fact that the evidence of intervention by toxins is fairly conclusive in some diseases, though less convincing in others. There is scope for much more work. It may seem an uninspiring conclusion to reach, but it does seem probable that we shall eventually find that toxins do play a part in producing disease symptoms, but only a part, other mechanisms of importance also being involved.

One issue of practical importance arises. Much progress in medical treatment has stemmed from the recognition that human disease symptoms may be due to toxins released by invading bacteria, and the use of immunization techniques based on antitoxin production has been of great value. Is it similarly possible that plant disease could be treated by neutralizing toxins released by the pathogen?

This approach was first suggested by Howard [18]. He produced evidence that many of the symptoms of the bleeding canker of maple, caused by *Phytophthora cactorum*, are due to toxin formation and claimed that alleviation of symptoms of the disease by systemic treatment of plants with diaminoazobenzene dihydrochloride was due to "antidoting" the toxin. Horsfall and Zentmyer [17] obtained similar results with Dutch elm disease (*Ceratostomella ulmi*) treated with diaminoazobenzene dihydrochloride or 8-hydroxyquinoline. By modern standards the evidence was not conclusive either that toxins were produced in these diseases or that the successful chemical treatments were "antidoting" toxins. In the fifteen years that have passed since these observations were made, no significant progress in disease control has been made by such methods.

Despite this initial lack of success, there is no doubt that Howard's idea of toxin-inactivation as a method of disease alleviation is theoretically sound, but three difficulties will be encountered in putting it into practice. (i) Any "antidote" will almost inevitably be specific for a single toxin, and identification of the toxin involved in any disease being studied will probably be a necessary preliminary to finding the "antidote." (ii) Even when a toxin has been identified it may be difficult to find an "antidote," and still more difficult to find a non-phytotoxic antidote! (iii) The usefulness of such a method of treatment will depend entirely on the significance of toxin-production in any given disease. Unless the disease symptoms are mainly due to toxin-production, any alleviation arising from the use of "antidotes" will necessarily tend to be marginal.

There is one possible line of investigation, however, which can in a certain sense be regarded as concerned with toxin-inactivation, that does offer some hope of practical benefit. As was pointed out earlier in this article, much damage may be done to host-plant tissues by enzymes secreted by invading parasites. Many bacterial and fungal pathogens release pectin-degrading enzymes in plants, causing considerable damage to the tissues, a typical effect being a soft-rot. Pectic enzymes, as we have seen, may also be concerned with symptom development in wilt diseases. In addition, the work of Brown [9] has shown that these pectic enzymes may also have a direct toxic action on plant cells. If, therefore, a specific inhibitor of such enzymes could be found, there is some prospect that by its use it would be possible to alleviate the symptoms of many plant diseases. But with this single exception, it is probable that, in our present state of knowledge, a search for better fungicides or fungistatic agents would be a more rewarding method of improving plant disease control than a search for toxin-antidotes.

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DIGESTION IN THE RUMEN

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Research in recent years has added much to our knowledge of the processes of digestion in ruminants, and this paper shows what has been achieved, with emphasis on physical aspects of rumen function and effects on the physiological economy of the cow. Study of the subject is the best approach to such problems as improved utilization of foods or control of metabolic disorders, and may lead to important advances in animal husbandry.

It is well to begin the story of digestion in the rumen with a reminder that all animals exist as a result of the ingestion—direct or indirect—of plants. Among those animals which rely exclusively on a plant diet ruminants are the most successful group of larger herbivors, and this success can be attributed largely to the efficient digestion of fibre achieved by them and to their consequent ability to use a wide range of plants as foods. The purpose of this article is to review the present stage of knowledge regarding the manner in which digestion proceeds in the rumen and to describe some of the secondary effects which this type of digestion has imparted to the physiological economy of the animal.

Although the rumen was developed primarily for the digestion of fibre, practically all the other food constituents are also broken down there. The breakdown is carried out by micro-organisms, and there are no enzymes originating from the animal. In the rumen there is a simultaneous synthesis of microbial polysaccharide and protein and of certain vitamins. Many products of this breakdown and synthesis are absorbed directly from the rumen into the blood.

Research into the ruminant process has been sporadic, and although important advances were made in France in the nineteenth century and in Europe and the United States between 1925 and 1935, the total number of workers in pre-war years was very small. At the present time, however, there is an unprecedented and world-wide spate of interest and investigation. This springs largely from the realization that the volatile fatty acids, long known to occur in the rumen, are not merely waste products, but in fact are the route by which much of the dietary carbohydrate is digested and absorbed. The rumen can no longer be regarded simply as a softening chamber, or even as an extra self-contained digestive compartment added to the digestive tract before the normal processes of gastro-intestinal digestion. It is becoming increasingly clear that possession of a rumen has profound effects on many aspects of the physiology of ruminants.

In the account which follows, the cow has been made the subject of most examples because this is the animal mainly used in my own experiments. For a similar reason the section on physical aspects of rumen function is the most detailed. No attempt has been made to provide a complete bibliography, but references have been chosen which will provide introductions to each aspect of

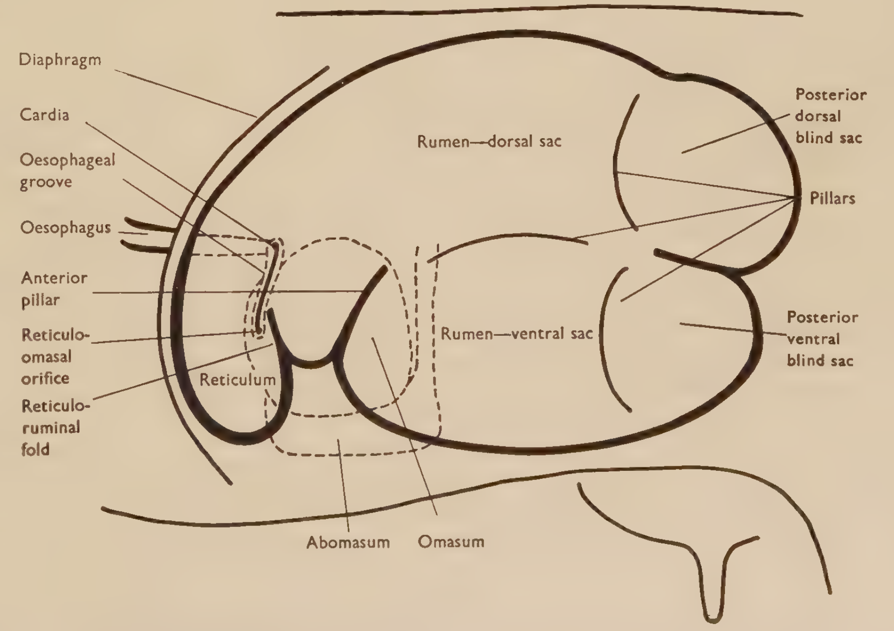

FIG. 1. Diagrammatical section through the rumen and reticulum of a cow, showing the approximate position of the omasum and abomasum.

the subject. Readers seeking greater detail should consult one of the reviews by Dr. Phillipson and his colleagues [10, 17, 18] or that by Dr. Huffman [13].

PHYSICAL ASPECTS OF RUMEN FUNCTION

Anatomy

The ruminant stomach is divided into four compartments: rumen, reticulum, omasum and abomasum. The rumen is a very large organ asymmetrically placed in the left half of the abdominal cavity. From the diagram in Figure 1 it can be seen that the rumen lies posterior to the reticulum, and the two are separated only by the reticulo-ruminal fold. For almost all purposes these two compartments function together, and it is usually more strictly correct to speak of the reticulo-rumen than of the rumen alone. The oesophagus enters the rumen at the cardia, whence two parallel ridges run over the wall of the rumen and reticulum to the reticulo-omasal orifice, which is the small opening (Figure 2) leading to the omasum. In the young animal these ridges, and a continuation in the omasum, can be raised and stiffened so that their edges touch, making a temporary tube down which milk passes directly to the abomasum; this is the oesophageal groove (Figure 1), and the circumstances governing its action have been studied extensively by Watson [25]. It will be noted from Figure 1 that, because of the close proximity of the entrance and exit, the reticulo-rumen is a vast cul-de-sac. It is, however, further divided into a series of compartments by the various muscular folds and pillars. These latter, with the muscles of the intervening rumen walls and those of the even thicker wall of the reticulum, enable the parts to contract in a powerful manner.

As shown diagrammatically in Figure 3, the omasum, which lies in a somewhat tilted position in the right half of the abdominal cavity (Figure 1), is a highly modified structure. Its internal space is largely filled by over one hundred thin leaves of tissue, some extending almost across the organ and others forming little more than ridges on the periphery. The wall of the lesser curvature of the omasum contains a strongly muscular pillar, otherwise the leaves and walls have few fibres. The omasum is more highly developed in cattle than in sheep or goats, and is virtually absent in camels and llamas.

TABLE I

RELATIVE CAPACITY OF DIFFERENT PARTS OF THE GUT

(Adapted from Colin [8])

Part of gut	Capacity (% of total capacity)			
	Ox	Sheep and goat	Horse	Pig
Whole stomach ..	70·8	66·9	8·5	29·2
Reticulo-rumen ..	60·2	57·4		
Omasum	5·3	2·0		
Abomasum ..	5·3	7·5		
Small intestine ..	18·5	20·4	30·2	33·5
Caecum	2·8	2·3	15·9	5·6
Colon and rectum	7·9	10·4	45·4	31·7
Total capacity (l.) ..	356	44	211	27

The inner surface of the rumen and the omasum is covered with papillae, the largest of which surround the reticulo-omasal orifice on the omasal side. Although the purpose of the papillae is not known, recent research in Britain [7] and the United States [24] showed that their early development was influenced by the type of food being consumed. Surprisingly, the chemical products of digestion appeared to exert a greater stimulating effect than the physical properties of the food. The lining of the reticulum is thrown up into the familiar reticulated or honeycomb-like ridges, from which the name is derived. The abomasum is the

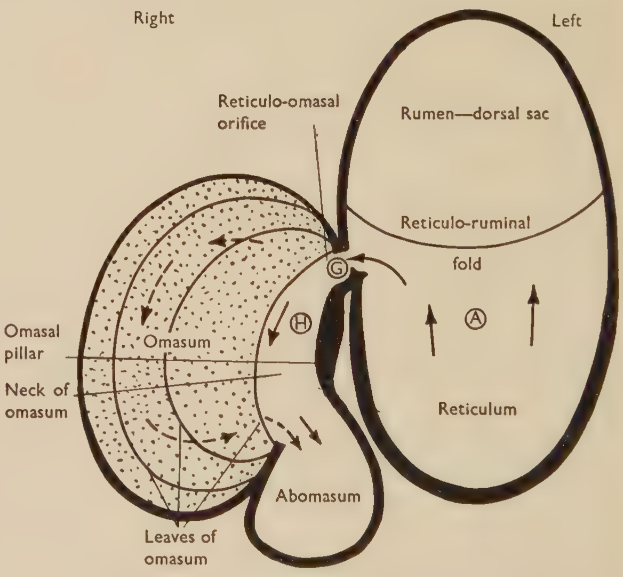

FIG. 2. Diagrammatical cross-section through the stomach of the cow to indicate the relationship of the reticulo-omasal orifice to the various compartments. In the animal the omasum lies flat against the rumen. The points A, G and H indicate the position of the recording balloons used to obtain the tracings in Fig. 9.

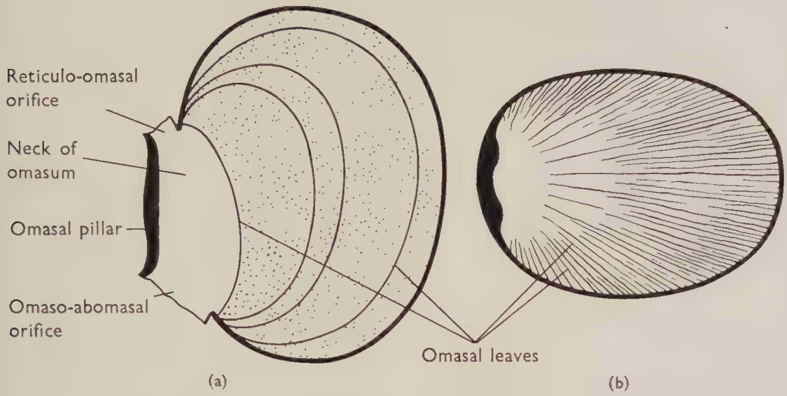

FIG. 3. Diagrammatical longitudinal section (*a*) and cross-section (*b*) through the omasum of a cow.

only one of the four compartments to have a secretory function. It corresponds, therefore, to the true stomach in non-ruminants, but is more tube-like than the stomach of man or the dog. Its walls carry a number of loose, spiral folds.

The relative sizes of the various compartments in adult ruminants are given in Table I. At birth the volume of the abomasum may equal that of the other compartments, but as the animal grows the ratio falls. Here again the nature of the food was found to influence early development. Experiments are being carried out at Shinfield on the effect of early feeding on digestive efficiency in the adult. The information suggests that even big differences in initial development will diminish during subsequent rearing on normal diets.

Study of digestion in the rumen has been greatly aided by the use of animals with fistulas in the dorsal sac of the rumen and elsewhere; animals so equipped suffer no pain, the cows have calves, give normal lactations and digest their food to the same extent as other cows. In cows at Shinfield the fistulas are normally closed by means of rubber cannulas, the centre of which can be removed for sampling (Figure 5). One of the many purposes for which the fistulas can be used is the complete removal, before weighing, sampling and return, of the contents of the reticulo-rumen. Values obtained by this technique are given in Table II to illustrate the large amount of digesta which are to be found in Shorthorn cattle receiving various diets. The lower amounts found during grazing were surprising and were discussed in detail by Balch and Line [4].

In ruminants the salivary glands are well developed and produce an abundant and continuous secretion. Since Colin [8], a great pioneer in ruminant research, made a tentative estimate of 60 l. (13 gal.) as the total daily saliva secretion of a cow, this value has been repeatedly quoted. It now seems likely that the daily production may often exceed twice this amount. The saliva of ruminants, however, contains no enzyme, so that until the food reaches the abomasum it is attacked only by enzymes of microbial origin.

TABLE II

SOME EXAMPLES OF AMOUNTS OF DIGESTA FOUND IN THE RETICULO-RUMEN OF SHORTHORN COWS RECEIVING VARIOUS DIETS

(Balch and Line [4])

Diet	Cow	Contents of reticulo-rumen		
		Total (lb.)	Dry matter (lb.)	Dry matter (%)
Hay alone	W22	166	18	11
Hay + concentrates	D15	156	19	12
Hay + concentrates	L32	164	22	14
Hay + beet pulp . .	K	175	18	10
Grazing	W22	130	12	9
	D15	129	11	8
	L32	114	9	8
	K	125	13	10

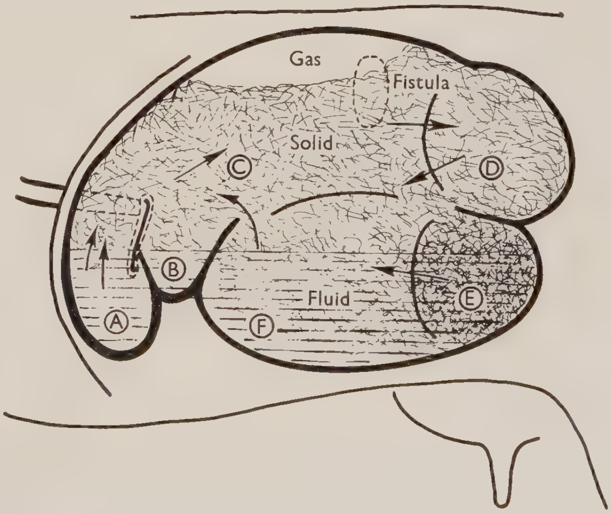

FIG. 4. Diagram indicating the arrangement of the fluid digesta in the reticulum and ventral rumen, the more solid materials packed in the dorsal and posterior sacs of the rumen and the gas bubble in the upper part of the dorsal sac. The points A–F are the positions of the recording balloons used to obtain the tracings in Fig. 7.

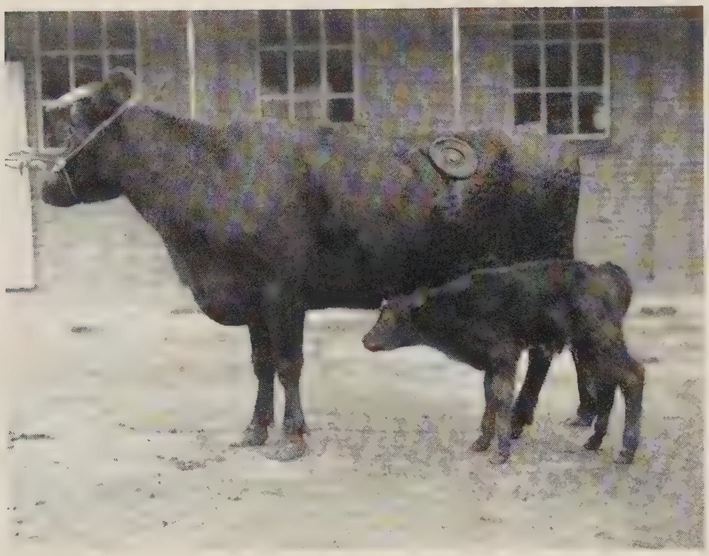

FIG. 5. Cow with a rumen fistula closed by means of a rubber cannula and bung. These cows are quite normal; they have calves and give normal yields of milk.

The anatomy is dealt with in great detail by Sisson and Grossman [22] and an account of this and other aspects of rumen function will also be found in Dukes [9].

Eating

In the mouth saliva is added to the food, and the mass is formed into a bolus about the size of a tennis ball before being swallowed. Concentrates are eaten so rapidly that the saliva added is only about a third of that added to hay. Some saliva is added even to grass and succulents.

The food boli pass down the oesophagus and enter the rumen through the cardia, plunging among the relatively fluid digesta in the anterior region. At the end of the meal it will be found that new hay, or other roughage, has been packed into the anterior region of the dorsal sac (Figure 4). If the meal contained concentrates or a succulent, such as fodder beet, many particles of these will be found in the same region. But a distinct tendency also exists for any food of small particle size, or which tends to absorb water rapidly, to accumulate in the ventral regions to a rather greater extent than hay. The importance and extent of this separation are sometimes exaggerated. There is always much mixing of foods with the residues from previous meals; this mixing ensures an early inoculation with rumen micro-organisms, and is brought about by the stomach movements.

Movements of the Reticulo-rumen

An excellent account of the movements of the reticulo-rumen has been given by Schalk and Amadon [20], who developed an operation for making rumen fistulas without knowing of the earlier French work [8]. Their use of diagrams similar to Figures 1 and 4, showing the relative positions of the organs in life, was an important contribution to ruminant nutrition.

The basic movement of the reticulo-rumen is a cycle of contraction beginning as a highly characteristic double contraction of the reticulum, followed by successive contractions of the anterior pillar, dorsal sac and ventral sac of the rumen. The path of this wave of high pressure is shown in Figure 4. It may be recorded by any kind of physiological tambour, or manometer and a kymograph. The modification shown in Figure 6 will make records over long periods and was used to obtain the tracings shown in Figure 7. The basic cycle of movement is often complicated by

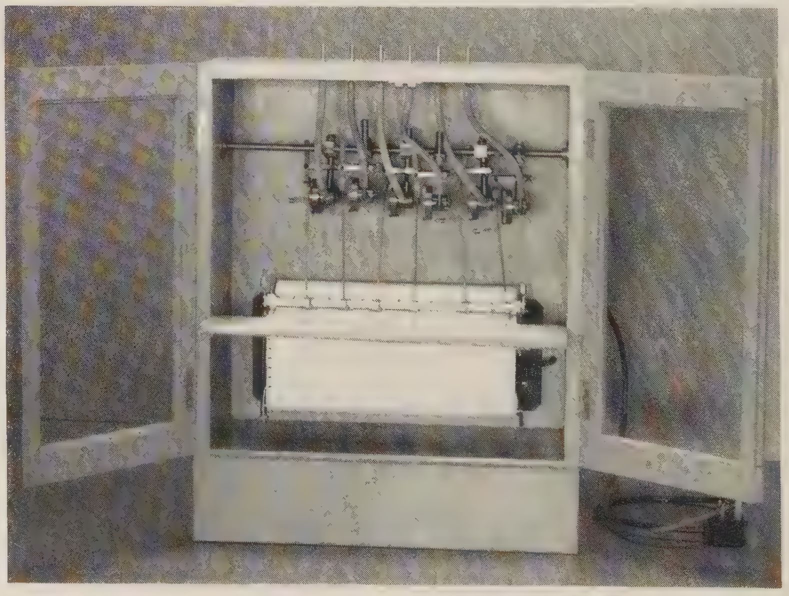

FIG. 6. The recorder used for recording rumen movements. Toy balloons in the cow are lightly inflated with air, which transmits pressure changes to the six tambours. These in turn operate the recording pens so that tracings are made on the moving sheet of paper.

movements of the rumen which do not involve the reticulum, by contractions within the smaller sacs of the ventral sac, and by omission of the contractions of certain parts. These variations merit further study: they complicate the interpretation of recordings of pressure changes in the rumen. In consequence, rate of movement of the reticulo-rumen is best estimated from recordings of the contractions of the reticulum, which show the number of basic cycles of contraction occurring in a given period of time. Such records have been collected at Shinfield from various fistulated cows receiving a number of diets over periods of up to two weeks' duration, and show that there are fairly distinct rates of contraction with different types of behaviour; there is also some difference between diets. The rate is always highest during eating and in a typical cow might then be 87 contractions per hour; it is usually slower when the animal is lying than when standing, and in many cows the rate is slower during resting than during ruminating. Thus, the normal rate in hours might be: standing resting, 63; lying resting, 57; standing ruminating, 66; lying ruminating, 63. Over the 24 hours the average rate is about one contraction per minute.

The cycle of movement brings about the arrangement of digesta shown in Figure 4, the drier and more fibrous parts of the food tending to be found in the dorsal sacs and posterior region, whereas the smaller particles and most of the fluid mainly appear in the reticulum and anterior and ventral rumen. Above the digesta there is usually a small amount of gas.

With each cycle of movement the fluid digesta are squeezed up and back over and through the mass in the dorsal sac along the path marked by arrows in Figure 4. Since packing of the mass is often very tight, the only distinct current to be seen at any one cycle is of fluids and finer particles. Even so, over a long period the mass itself is gradually kneaded, turned, mixed and eroded. Between the cycles little free fluid will be found in the dorsal sac; but, as the cycle begins, the permeating fluids can be seen first rising through the mass and then sinking into the ventral sac. By this means substances in solution and finer particles are leached from the main mass of digesta and, at the conclusion of the active part of the cycle, are returned to the reticulum and anterior and ventral rumen. Larger particles are less likely to follow this route until they have received further chewing.

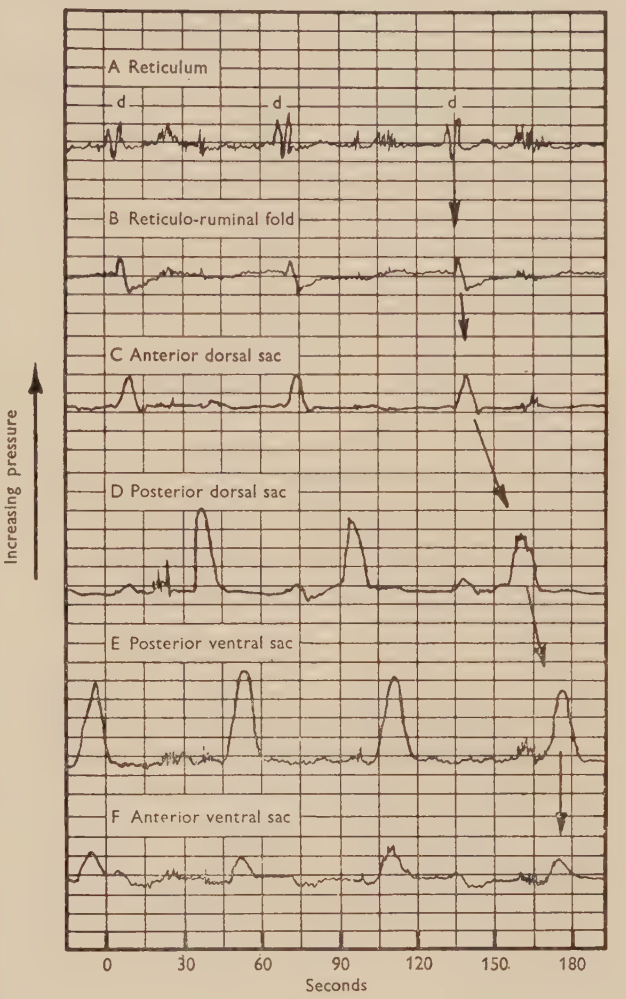

FIG. 7. Records showing three cycles of pressure changes in the reticulo-rumen of a resting cow. The position of the recording balloons A–F are shown in Fig. 4. The progress of the third cycle is marked by arrows on the recording.

Rumination

Chewing the cud is the most striking manifestation of the rumen process. It reduces particle size and thereby increases the chance of any given particle subsequently leaving the reticulo-rumen; yet this tendency is far from immediate, and many of the particles re-enter the rumen after rumination. Chewing greatly facilitates bacterial attack.

Regurgitation of digesta to the mouth is brought about by a complicated reflex involving (i) an extra contraction of the reticulum and (ii) breathing in with the glottis closed. At the same time the lower part of the oesophagus, adjacent to the cardia, forms a funnel-like opening into which digesta pass as a result of the combined effects of a raised pressure caused by the reticulum contraction and a lowered pressure in the oesophagus

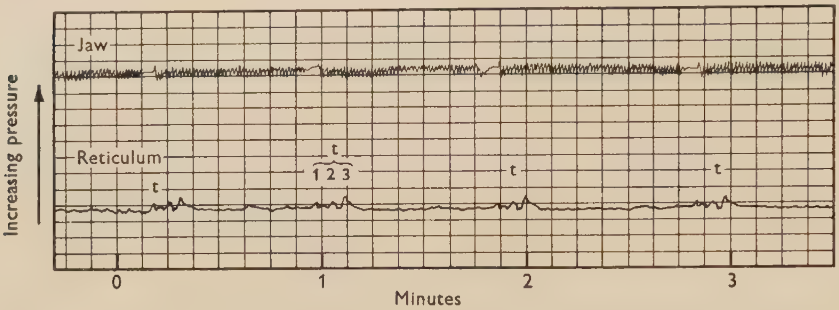

FIG. 8. Records showing the movements of the jaw and pressure changes in the reticulum of a ruminating cow. The upper balloon was placed under one of the straps of a leather head-stall. The triple contractions of the reticulum (*t*) are marked.

caused by the inspiratory effort. The cardia immediately closes and the digesta are carried rapidly to the mouth by reverse peristalsis. The stimulus for this reflex is the presence of fibrous food in the reticulum and anterior rumen. When finely ground, roughage loses the ability to evoke the reflex.

During rumination the jaw movements are characteristically steady, broken by the short intervals of 2–4 sec. required for the chewed bolus to be swallowed and a new one regurgitated (Figure 8). A slight pause often occurs, soon after the regurgitation, when unwanted fluid is swallowed. Saliva is added during the chewing, but the amounts concerned are not known accurately. Most periods of rumination last 20–50 min. and it is unusual for one to continue for over 90 min.; they tend to be longer and more frequent soon after the end of periods of eating. It would be of value to know to what extent the material being regurgitated at such times consists of newly ingested food and to what extent of residues from earlier meals; these points are still not fully understood.

After chewing, the bolus of rumination is returned to the rumen and the sloppy mass is deposited in the anterior dorsal sac, in the same manner as the bolus of eating. It does not, as was formerly supposed, pass down the oesophageal groove; instead the particles may chance to become part of the mass in the dorsal sac or to pass to the ventral sac or to the reticulum. In either instance some of them will probably be chewed more than once, but as a result of the chewing the chances of some entering the reticulum and then passing to the omasum are increased.

A good many observations have now been made on the time spent daily in rumination. With many diets the total is in the region of 7–11 hours. Tribe [23] has reviewed recent work on the behaviour of ruminants. Gordon [12] made the interesting observation that in the sheep the periods of rumination, and the total time spent daily in rumination, are determined much more by habit than by the amount of roughage being consumed.

Eructation

Gas formed during fermentation is removed by eructation or belching. Failure to remove the gases can lead to the familiar disorder—bloat. Weiss [26] has described a special rumen contraction by which, it is claimed, the bubble of gas is pushed forwards and down to the cardia before removal. Among the many theories that have been advanced for the cause of bloat one is that the belching reflex is prevented by a toxin and another that the cardia becomes so immersed in the fluid layer that the gases cannot reach it. Work done in New Zealand has now suggested that, in perhaps all cases of bloat, the entrapping of gas bubbles among the digesta as a froth is an important feature. Successful current therapy includes the administration of oils or other substances to prevent froth formation and the feeding of antibiotics to prevent gas formation. The subject of bloat has been reviewed in this journal [11].

Action of the Reticulo-omasal Orifice and of the Omasum

There is no general agreement about either the mechanism governing the passage of food through the reticulo-omasal orifice or the purpose and action of the omasum. The process must be efficient and fairly rapid, because in a cow consuming 20 lb. dry matter daily something approaching 14 lb. dry matter might have to pass through the tiny orifice daily, the remainder being absorbed; this would mean over 0·5 lb. dry matter per hour or 4 litres of reticulum content per hour. The following account is based on my own observation [3], but some of the details are disputed by other workers.

When the arm is inserted through the rumen fistula the orifice can be felt to be normally open—the opening being 1·0–1·5 in. in diameter—and a collection of coarse roughage can always be found in the neck of the omasum close against the orifice. The level of fluids in the reticulum is almost invariably above the level of the orifice (Figure 4). At the time of the first reticulum contraction the orifice is closed; at the time of the

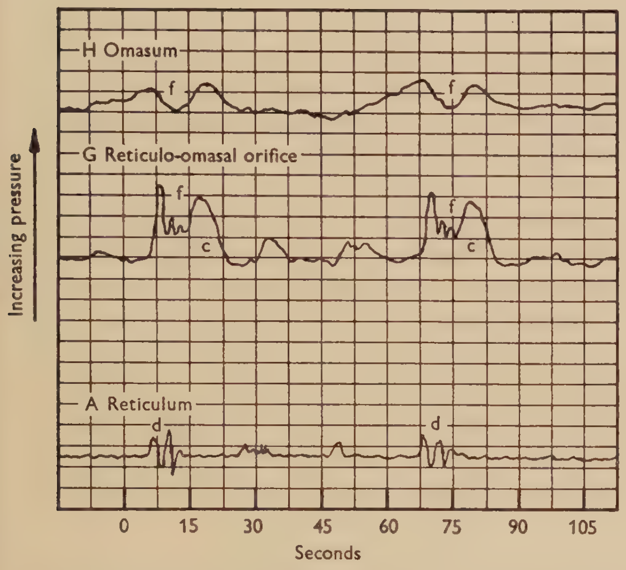

FIG. 9. Records showing pressure changes in the reticulum, the reticulo-omasal orifice and the omasum of a cow. The double contraction of the reticulum (*d*), the sudden fall in pressure in the omasum and in the orifice (*f*), and the powerful contraction of the orifice (*c*) are shown.

second contraction it is open (Figure 9), but immediately closes strongly for about 12 sec. Recordings of pressure changes in the omasum (Figure 9) show that the pressure there begins to rise before the first reticulum contraction, and falls sharply at the time of the second contraction. On this evidence a flow of the highly fluid digesta from the reticulum to the omasum seems most likely to occur at the time of the second reticulum contraction. Considerable sieving must occur at the orifice, because of its small size, its setting in relation to the flow from the reticulum, the lining of large papillae and the mass of fibrous digesta in the omasal fundus. It follows that the chances of a small particle leaving the reticulum are greater than those of a large particle. The essential feature of rumination seems to be the reduction of the digesta to a small particle size so that this passage may continue. Ground concentrates or ground hay tend to leave the reticulo-rumen more rapidly than unground hay eaten at the same time.

The co-ordinated, valve-like action of the omasum, orifice and reticulum continues night and day irrespective of the behaviour of the animal. Contraction at the faster rate during eating implies a more rapid transfer of digesta to the omasum at that time, and this has been demonstrated. Ideally, this transfer should consist mainly of residues from earlier meals, but it is not known to what extent the new and the old can be separated. It is certain that, at best, there can be no more than a tendency for the new to be stacked in the dorsal sac and the old to pass onwards. Gordon [12] has obtained evidence that the passage of particles from hay is greatest during rumination.

At the slaughterhouse it is readily seen that the digesta lying between the leaves of the omasum are dry (19–25% dry matter) and consist entirely of fine particles, whereas those in the neck are more fluid (15–19%) and have a larger particle size. This has led to the theory that the leaves grind or "triturate" the food; but a grinding function has never been proved, and it is my view that most particles of solid digesta pass through the neck of the omasum without going between the leaves. The second peak of pressure in the omasum could represent a movement in which the newly entered fluid digesta are pressed against the edges of the leaves, so that water and some fine particles pass between the leaves while most of the solid digesta tend to pass, in a drier state, to the abomasum. The first peak of pressure may effect the onward passage through the large omaso-abomasal orifice. Were the digestive secretions of the abomasum added to unconcentrated reticulum

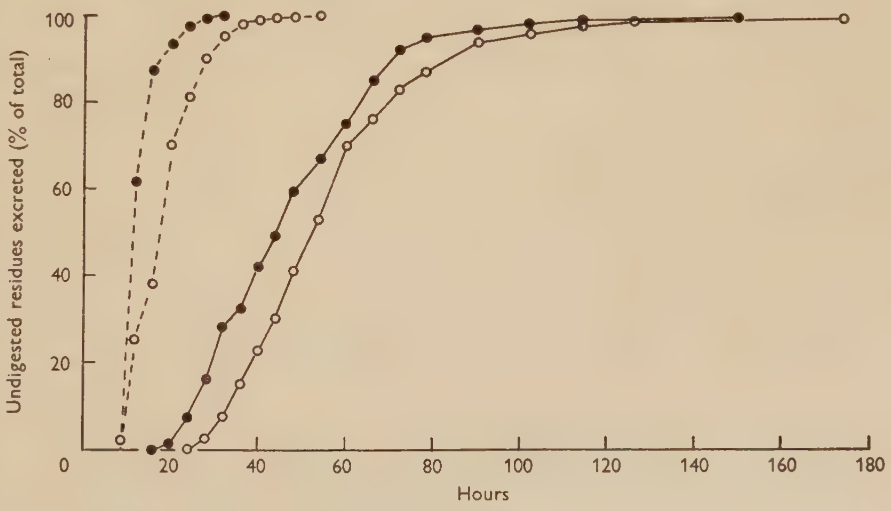

FIG. 10. The excretion in the faeces of undigested residues of (i) a meal of stained hay (solid line) and (ii) stained ground hay which was placed in the abomasum at the start of the meal (broken line). Values are shown for two cows, ● and ○.

contents the efficiency of the gastric enzymes might be impaired, and the resulting volume would require a more rapid rate of passage and a consequent reduction in the time available for digestion in the hind gut. It would be interesting to know how camels and llamas overcome this difficulty.

The presence of rumen, reticulum and omasum causes a considerable delay in the overall rate of passage. Figure 10 gives typical curves for the rate of passage of stained hay and shows the great reduction in the time required for excretion when stained ground hay was placed directly in the abomasum. This delay allows time for the rumen micro-organisms to attack the digesta.

Rumen Micro-organisms

Study of the organisms living in the rumen presents special problems and great interest has been shown recently in this difficult field, yet less is known about the types, numbers and detailed function of the organisms than about the gross chemical changes they bring about. The numbers of living bacteria are very large, and concentrations as great as 10^{11}/ml. of rumen fluid have been reported. Whatever be the diet of the animal, many species of bacteria will be found in the rumen. When withdrawn from the teeming association in which they normally live, cultivation in pure culture may be difficult, especially of the cellulose-decomposing organisms. Because behaviour in pure culture may differ from that found in mixed strains and species, it is also difficult to associate any one organism with any given chemical reaction. It does not even follow that those present in largest numbers are necessarily the most important. With diets consisting mainly or entirely of hay *Streptococcus bovis* appears to be the predominant organism, while with increasing amounts of concentrated foods, and especially of flaked maize, the lactobacilli tend to predominate. These changes are accompanied by changes in the end products of digestion. The use of serological techniques is greatly improving the precision of these studies and has shown that a high proportion of the bacteria belong to known species and strains [6, 14]. We still do not know, however, whether the ruminant obtains its bacteria by chance from its food and surroundings, or whether these are specialized types acquired by contact with other ruminants. Use of rumen inocula in early life seems to be beneficial only when calves are rigorously excluded from contact with adult cattle; there is, however, a case for the use of inocula at any age when for some reason the population of the rumen has been disturbed.

The rumen also contains great numbers of ciliate protozoa. These belong to several species and can be identified microscopically. Their numbers may be as great as 10^6/ml. of rumen fluid, which implies that their biochemical activity must approach that of the bacteria. Some species can attack dietary carbohydrate, and ingestion of bacteria is known to occur [16].

Both types of rumen micro-organisms require sources of energy, minerals, nitrogen, certain vitamins, and possibly other factors. In the shortage or absence of any of these, growth will be impaired. This can be readily demonstrated *in vitro*, but such shortages seem unlikely to be of great importance in British systems of management.

FATE OF FOOD IN THE RUMEN

On arrival in the rumen the bolus of food enters an environment highly suitable for microbial fermentation. At the start of the meal, at least, the *p*H will be only slightly below neutrality, the temperature will remain at 39° C, and the food itself will already have been saturated to a greater or lesser extent with highly buffered saliva having a strong wetting effect. Bacterial attack is therefore immediate, and evidence of digestion can be obtained as little as 15 min. after eating has begun.

Carbohydrates

Under farm conditions practically any meal will supply the cow or sheep with carbohydrates, ranging from the simplest sugars to the complex fibrous celluloses. These are all broken down by the micro-organisms to the same limited end products, although at rates which differ greatly in different carbohydrates. The result is a mixture of the volatile fatty acids—acetic, propionic and butyric—with perhaps some lactic acid; water, carbon dioxide and methane are also produced during the fermentation.

With diets of hay alone, or with only small amounts of concentrates, the mixture of acids found in the rumen might consist of: acetic, 70%; propionic, 17%; butyric, 10%; traces of valeric and higher acids, 3%. When the diets are rich in sugars or starch the proportion of acetic falls and that of propionic rises, so that in extreme cases, e.g. in a cow receiving 2 lb. hay and 24 lb. concentrates, the proportions may be 41% acetic and 39% propionic. With a diet consisting entirely of hay the production of acids is so regular that there is little rise and fall over the day in either their concentration or the *p*H of the rumen contents. With increasing amounts of concentrates the acids tend to be produced more rapidly after feeding, often with a peak of concentration and acidity 3–4 hours after the beginning of the meal, and with a pronounced rise and fall in concentration during the 24 hours. If a food particle contains both cellulose and starch and there is ready access for bacteria to each, the starch will be attacked more rapidly and hence be completely digested sooner than the cellulose. For this reason it is inevitable that much of the more readily digestible carbohydrates, which could be dealt with by the hind gut, will in fact be digested in the rumen. There is evidence that the digestion of cellulose proceeds more rapidly in the fluid digesta of the ventral regions than among the drier digesta of the dorsal sac, and it is also well established that the breakdown of cellulose is impeded by the presence of starch.

There is some incorporation of carbohydrate into microbial polysaccharide, especially in the protozoa, in which the granules of starch can be demonstrated by suitable staining. The amounts transferred to the abomasum in this form are, however, not thought to be very large.

Fat

Diets for ruminants rarely contain more than about 3% of true fat. There is evidence that the main effect of the rumen organisms on the dietary fat is one of hydrogenation of the unsaturated acids, such as linoleic and linolenic. This may account for the small amounts of these acids found in the body fat of ruminants. It has been suggested that excessive hydrogenation of these essential dietary acids could result in a shortage of them for body function, but these possibilities have as yet received little attention.

Protein

Ruminants obtain their protein mainly from plant sources. Some foods, such as silage and some of the root crops, contain an appreciable proportion of their nitrogen in a non-protein form, and nitrogen is also added to the rumen in the form of urea in saliva. A considerable, though as yet undetermined, fraction of the dietary protein probably escapes attack in the rumen and is then digested in the hind gut. Proteins may be broken only as far as amino-acids, or completely to yield ammonia and certain fatty acids as the end products. With soluble proteins, such as casein or the protein of groundnut, the production of ammonia is very marked. Much ammonia is also produced from the protein and other nitrogenous compounds of young grass. A large proportion of this ammonia is then lost by absorption, conversion to urea in the liver, and excretion. With young grass ammonia can often be detected in peripheral blood. As the following section will show, reduction of nitrogenous compounds to ammonia does not necessarily represent a complete loss to the animal.

Synthesis of Protein

It has long been realized that under some circumstances ruminants can use simple nitrogenous compounds as sources of protein. Some rumen bacteria are able to build the compounds up into protein, and the bacteria are themselves digested in the hind gut. An extensive literature, reviewed by Reid [19], deals with experiments in which urea has been included in the diet of farm animals. The synthesis of protein from simple nitrogenous compounds in the food, from urea in saliva and possibly from simple compounds entering the rumen from the blood, is clearly a normal process. It appears to be most efficient in the presence of the more readily digestible carbohydrates, especially starch. In some countries it is considered profitable to add urea to commercial feed mixtures, but the experiments which have been completed in Britain, particularly with milking cows, have been less encouraging than some of those abroad. It is necessary to know more about the factors controlling protein synthesis in the rumen and also about the protein requirements of farm ruminants, before greater use can be made of this process.

Synthesis of Vitamins

Some rumen organisms, principally bacteria, are able to synthesize the water-soluble vitamins of the B group, should these be lacking in the diet. Ruminants are accordingly independent of a supply of these vitamins, which seem to be produced when required from almost all diets, although an adequate supply of cobalt must be available for synthesis of vitamin B_{12} [15].

The fat-soluble vitamins are not synthesized by the rumen flora.

Absorption from the Rumen

A unique feature of the ruminant stomach, as opposed to the simple stomach of man, dog or

TABLE III

SOME EXAMPLES OF THE EXTENT OF DIGESTION IN THE RETICULO-RUMEN AND IN THE REMAINDER OF THE GUT (HIND GUT) OF DAIRY COWS

(Tentative values from Balch [1])

Diet	Cow	Apparent digestion coefficient							
		Dry matter		Crude protein		Nitrogen-free extract		Crude fibre	
		Reticulo-rumen	Hind gut	Reticulo-rumen	Hind gut	Reticulo-rumen	Hind gut	Reticulo-rumen	Hind gut
12 lb. hay	W22	50	21	24	43	62	16	49	20
16 lb. hay, 10 lb. concentrates	H	37	23	7	45	56	12	25	23
16 lb. hay, 20 lb. concentrates	H	44	27	24	50	63	18	27	20
14 lb. hay, 6 lb. beet pulp ..	D15	31	30	1	43	46	22	32	27

rat, is that direct absorption of nutrients into the portal blood system—carrying blood from the gut to the liver—occurs to a significant extent. The possibility of absorption was demonstrated in the early 1930s and is now known to include water, the fatty acids, glucose, ammonia, vitamins, and many inorganic ions. It is not yet clear whether the transport of ions through the rumen wall is entirely passive, depending on the concentration gradients, or whether the wall plays a selective rôle. In the case of the fatty acids it has been shown that butyric and to lesser extents propionic and acetic acids are metabolized in the wall, so that the mixture of acids in the portal blood differs from that in the rumen.

Owing to the difficulty of obtaining samples from, and of measuring the rate of flow of blood in the portal vein, it is hard to estimate the amounts of nutrients being absorbed from the rumen under conditions at all close to normal. Estimates have, however, been attempted, notably by Schambye [21]. They suggest that a considerable part of the energy obtained from the food is in the form of volatile fatty acids. Absorption of glucose occurs to only a very limited extent. The technique is still not sufficiently precise to enable comparisons to be made with, for example, different diets.

Extent of Digestion in the Rumen

By collecting samples of digesta thought to be representative of those passing through the reticulo-omasal orifice, and use of the indigestible dietary lignin as a marker, it has been possible to estimate the extent of digestion in the reticulo-rumen [4]. For instance, if the ratios of a given nutrient to lignin were four to one in the food and two to one in the sample of digesta, it follows that 50% of the nutrient had been digested. Some provisional values obtained by combination of this method with a normal digestibility trial are given in Table III. They support the view that the digestion of carbohydrates (nitrogen-free extract and crude fibre) is mainly accomplished in the rumen, whereas that of protein occurs to a greater extent in the hind gut. The values given for crude fibre in Table III are surprising, and further experiments are necessary to determine whether the importance of the hind gut has been exaggerated by the method of measurement. The absorption of fats, fat-soluble vitamins and certain of the inorganic constituents (ash) seems also to occur mainly in the hind gut. Measurements of the extent of digestion in different parts of the gut have been attempted by other methods, usually requiring the slaughter of the animal.

Rôle of Water in Rumen Function

Water plays an important part in all aspects of the rumen process. The transport of solid particles within the rumen, to the mouth for rumination and onwards to the omasum, are all carried out as a watery suspension; the leaching action of the fluids on the mass of digesta in the dorsal sac and the vital rôle these must play in the process of absorption from the rumen have all been noted earlier. This importance may well be signified in the development of the omasum if, as seems likely, the primary function of that organ is to absorb water and substances in solution. For all this there must not be too much water in the rumen, because that would cover the cardia and interfere with belching; for a similar reason ruminants cannot lie for long on their backs or sides. In each cow there seems to be a marked tendency for the dry matter content of the digesta to be similar with different diets, even if the intake of water is varying greatly. The dry matter content is usually lowest during grazing.

FUTURE RESEARCH ON RUMINANTS

The great and immediate problem in the physiology of the rumen is the quantitative assessment of the processes now known to exist and the effect on them of different diets. Research may lead to means of improving the utilization of foods either by promoting more efficient digestion or by preventing losses of nutrients. In this connection search is now being made for dietary factors which stimulate bacterial breakdown of carbohydrate, and several compounds active *in vitro* have already been found. One school of thought also seeks means of excluding from the rumen foods that can be digested elsewhere in the gut. It seems unlikely that either of these will lead to changes in standard practice for some time.

Considering the overall economy of the animal, it is clear that the new knowledge of the rôle of the different fatty acids in carbohydrate breakdown is likely to dominate the bold new attempts now being made to straighten out the muddle which has for so long confused our system of measuring the energy requirements of ruminants and the energy value of foods for ruminants [5]. In a more limited bodily activity it has already been shown that diets which cause the production in the rumen of more propionic acid and less acetic acid than usual also cause the milk fat content to fall. This is apparently due to a shortage of acetate for milk fat synthesis in the udder [2]. There may be other instances where the proportions of the fatty acids are of importance to the animal. Better knowledge of the rumen process may also lead to clarification of that other thorny problem, the protein requirements of ruminants. Is it too late to hope that simple and cheap nitrogen compounds may yet be used with confidence as sources of protein?

As methods of husbandry become more intensive the incidence of the so-called metabolic disorders appears to increase. These are bloat, ketosis or acetonaemia, hypomagnesaemia or grass tetany, milk fever, and possibly others still uncharacterized. Since to a greater or lesser degree the rumen is implicated in most if not all of these, their conquest must depend on a better understanding of the rumen process and is essential if the trend towards more intensive management is to continue. In this field also much work can be expected in the next few years.

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BOOK REVIEWS

Forest Soils. Their Properties and Relation to Silviculture. S. A. Wilde. Pp. ix + 537, with line and half-tone illustrations. The Ronald Press Co., New York. 1958. $8.50 net.

This is a most refreshing book. Prof. Wilde has written a textbook in which he devotes much more attention to the living than to the non-living part of soils. Soils are described and discussed not so much in relation to their geology, chemistry and physics as in relation to the forests which they carry and which are regarded as integral parts of the soils. Chemistry and physics are adequately treated in relation to ecology, but throughout the soil is regarded as a product of the forest rather than *vice versa*.

The book is in two parts, the first dealing with soil as a medium for tree growth, and the second with the applications of soil science to silviculture. There is a good description of the extremely complex life of the forest floor and of the many different types of humus to which its activities give rise and which play such a vital role in forest economy. The author has perhaps too great a fondness for inventing new terms which, though usually well named, tend to confuse the reader by their multiplicity. The ordinary reader may not grasp the full significance of the statement that crypto-mull is a leucorganic endohumus similar to velum until he has read further where everything is explained in orthodox English. The important point is continuously emphasized that one cannot generalize freely about soil–forest relationships, and that what is valid in one climatic or geological region may not be valid in another. The author roams the whole world for examples and illustrations of his points and—what is unusual in an American textbook—cites more foreign than American references. His outlook is reflected in his assertion that a geological stratum cannot be a "parent rock" because a parent should be alive and that "the relationship of soil and forest growth . . . is anchored in the law of probability, in its own theory of relativity, and in the principle of uncertainty."

In the second, and shorter, part of the book the main aspects of silvicultural practice dealt with include the maintenance of nursery-soil fertility especially by the use of fertilizers, soil survey for the selection of sites suitable for different trees, the diagnosis and treatment of forest-soil deficiences, the effects of silvicultural treatments on the soil, and the adjustment of forest management to the productive potentialities of the soil. As soon as one gets into the field of applied soil science, soil science is liable to be forgotten to a large extent and to be replaced by common sense. Chemical fertilizers are listed, machines for and methods of soil cultivation and soil conservation are described, as also are the principles of land survey and improvement, the selection of planting sites, reafforestation, etc., but when all is said there is very little soil science in it. The forester, however, should find this part none the less useful for that. It shows how the simple facts of soil properties, which any forester can recognize when he has mastered the jargon, can be applied to the betterment of the forest.

The book is well written and very well illustrated and diagrammed. G. V. JACKS

Control of the Plant Environment. (*Proceedings of the University of Nottingham, Fourth Easter School in Agricultural Science*, 1957.) Edited by J. P. Hudson. Pp. xvi + 240, with line and half-tone illustrations. Butterworths Scientific Publications, London. 1957. 42s. net.

An intrinsic problem in the study of plants and animals is that their nature at any given time has been partly determined by the history of their nurture. Although the genotype of an organism may be distinctive, its expression will vary according to the conditions met in the course of its growth. There can therefore be no absolute concept of what a daisy or an oak tree looks like, because an ideal environment in which the ideal daisy or oak tree might grow is inconceivable. Biological material and natural environments are notoriously variable, and the variation in each makes the study of the other more difficult.

Geneticists have contributed to reducing the "error" in biological experimentation by breeding for uniformity in experimental organisms, e.g. inbred populations of closely similar genotype, highly uniform F_1 progeny obtained by crossing inbred lines (e.g. maize or hospital mice) or clonal material. Natural environments cannot be standardized in this way, and so either the design of experiments has to take into account the natural variations or unnatural controlled environments must be created. If they are to be of real value to the biologist, such controlled environments must be capable of being accurately and simply described (only a stable environment can be simply described) and accurately repeated. There are at least 70 installations at universities and research stations in Britain providing more or less controlled environments for plant growth, and this book places on record papers given by "physicists, chemists, engineers, biologists, agronomists, agriculturalists, horticulturalists—all with a common interest in environmental control."

The control of environments with any degree of accuracy is expensive, and the most luxurious is still the famous "phytotron" of F. W. Went at the Earhart laboratory at Pasadena, California. More recently such "organizations" for environmental control have been set up at Liège and at Wageningen. Papers at this symposium described the organization of these phytotrons as well as a wide range of simpler and cheaper forms of complete and partial control of the physical environment represented by glasshouses, growth rooms, temperature-controlled rooms and growth cabinets (these terms are defined in an introductory section, which should help to check their indiscriminate usage).

One of the greatest benefits which the publication of this symposium may bring is that it will help a research department more easily to cut its coat to suit its cloth. One is left with the strong impression that the more elaborate coats (phytotrons) have been cut before the style and the cloth (experiments) had been precisely considered. It is probable that delicate and simultaneous control of light, temperature, humidity, soil water supply and nutrient level are rarely required in experiments on plants. For this reason it is likely that the simple growth cabinets and rooms will prove of greatest value to research workers.

At present laboratories lacking some means of controlling the environment are somewhat out of fashion, and much money is spent on producing newer and better models. It is impossible to measure and compare scientific achievement, but it is interesting to speculate how much of the money could have been better spent in training more research workers in the art of designing field or pot experiments and using techniques of growth analysis and statistical methods for the interpretation of environmental factors.

Fifty-three papers are published in this volume together with comments made in discussion; many most valuable points arose in the interchanges after each paper. The symposium is a well-edited record of a stage in the development of a technique. Experimental control of the plant environment is, however, only a means to an end, and so far no very striking advances have stemmed directly from it. Combined with the use of homogeneous genetic material, controlled environments offer the ecologist, physiologist and agronomist the possibility of simplifying experimental design and reducing error. The most fascinating problems of biology, however, still concern the behaviour of varied and changing organisms in changing environments. In the passion for control this may easily be forgotten.

J. L. HARPER

The Experimental Control of Plant Growth. F. W. Went, with contributions by W. C. Ashby, L. T. Evans, A. W. Galston, H. Hellmers and W. M. Hiesey. Pp. xvii + 343, with line and half-tone illustrations. Chronica Botanica Co., Mass., U.S.A. 1957. $8.50 net.

Professor Went has pioneered a far-sighted experiment in methods of studying the living plant. The results of his early work on the behaviour of plants in controlled environments convinced him of the desirability of producing and controlling a set of environmental conditions on such a large scale that within one building plants could be studied under almost any condition of light, temperature, wind or rain. Through his enterprise and imagination this project was realized, and nine years ago the Earhart Laboratory of the California Institute of Technology was built. Now, with the co-operation of some of the botanists who have come from many lands to use these special facilities, Professor Went has recorded the development and work of this laboratory from its earliest days.

The book is divided into three sections. Part 1 (93 pages) describes the construction, operation and layout of the building, with detailed descriptions of the greenhouses, artificial light rooms, laboratories, workshops and control rooms. The maintenance of the vast electrical machinery, the routine of technicians and gardeners and the schooling of research workers is discussed at length. The methods of growing disease-free plants, and the problems of ensuring a relatively sterile environment make fascinating reading, and provide invaluable information for those seeking to control environmental conditions on even the most modest scale.

Part 2 (95 pages) summarizes experiments on the growth and development of selected species. Many of the results are of practical interest to the agriculturist, horticulturist and agronomist and serve to demonstrate the great value of these critical laboratory studies as a prelude to successful investigations in the field. Part 3 (134 pages) is devoted to a general discussion of physiological problems and includes substantial chapters on growth analysis and photosynthesis. Unfortunately the scope of this book precludes a full discussion of these results in relation to those obtained in other laboratories. Chapters on plant climatology, ecology and germination deal with the responses of plants to individual and integrated climatic conditions, and indicate the many problems which will repay this type of experimentation. The short chapter misleadingly headed "Biochemistry" describes two experiments on the effects of auxin and adenine on plant growth but contains no biochemical discussion of the results. There are 25 plates at the end of the book, and it is a pity that in a few of the photographs of crowded plant material it is difficult to see vegetative details. The 71 graphs and diagrams are not all of the high standard we have come to expect from American publications, for the lettering lacks uniformity and is sometimes too small or compressed for easy interpretation. But these are minor criticisms. Professor Went has presented an enthusiastic account of the Earhart Laboratory and the important contributions that have been made there to our knowledge and understanding of the behaviour of the living plant. That other countries have built or are building "phytotrons" of their own is a testimony to the success and value of this remarkable undertaking.

D. J. OSBORNE

Principles of Plant Pathology. E. C. Stakman and J. George Harrar. Pp. xi + 581, with line and half-tone illustrations. The Ronald Press Co., New York. 1957. $8 net.

Plant pathology is a rather diffuse science, and the proper assessment of a disease in the field requires knowledge of the host's physiology and the ecological conditions which favour its growth. This knowledge in itself may provide a key to the solution of a disease problem which is not associated with a parasite or one in which a change in cultural conditions may tip the ecological balance against it. When a parasite is involved, however, its weaknesses must also be studied by themselves and in relation to the general development of the host. It is relatively easy to explore the possibilities of chemicals in the control of specific diseases, but these provide only one—probably not the most important—line of approach. A genetic study of the resistance of the host may lead to the production of resistant varieties, and a study of the variability of the pathogen may indicate how long such varieties are likely to remain useful.

Principles of Plant Pathology represents a very valuable and successful attempt to collect information of this type and to present it as a unified whole to the student. Of the 542 pages which form the body of the book about 300 are devoted to such general topics as the physiology and genetics of the hosts and pathogens and the spread of plant disease. The remainder provides a general background: about 80 pages cover the classification of diseases in its widest sense and include a useful section on mineral deficiences; about 90 pages deal with control measures, and only about 60 are devoted to descriptions of specific diseases. This is in marked contrast to the balance in conventional books on plant pathology, which devote one-half to two-thirds of their content to the description of specific diseases. The result is a book which does not attempt to provide answers to specific questions but performs the far more valuable task of providing the background knowledge necessary to a real understanding of plant pathology as a science.

The volume is well produced and lavishly illustrated. The references at the end of each chapter provide a guide for further reading in the subjects discussed. One appendix lists some of the more important books with which the plant pathologist should be familiar, and a second the principal plant pathogens cited in the text. In addition there are indices of subjects and authors.

The book is one that all plant pathologists should study. It will be of particular value to students, and it is to be hoped that the price will not discourage them from owning a copy. Much might have been done to reduce the cost of the volume by eliminating the less relevant illustrations and compressing certain introductory sections, which are unnecessarily elementary for readers who are sufficiently well versed in the subject to appreciate the body of the book. It would be a great pity if the circulation of this volume were to be reduced by the expense of unnecessary frills.

S. H. CROWDY

ABSTRACTS

CROP PRODUCTION

Studies of the growth of cereals on seedbeds prepared by dry-sieving of the soil. R. S. Edwards, *Emp. J. exp. Agric.*, 1957, **25**, 167–84.

Soil was separated into five aggregate sizes by sieving; half the plots were consolidated by applying an even pressure with a board. The crops were spring barley (3 years) and winter oats (2 years). Fineness of soil accelerated germination and slightly increased the percentage emergence in all cases. Coleoptiles in the coarsest seedbeds often emerged at an angle, owing to mechanical impedence. Consolidation accelerated the date of emergence but reduced the percentage emergence of winter oats; it had no effect on spring barley. S.F.A.

The effect of seed rate and nitrogen on lodging and yield of spring barley (Field experiments 1954 and 1955). M. D. Glynne and D. B. Slope, *J. agric. Sci.*, 1957, **49**, 454–8.

In trials carried out in 1954 and 1955 at Rothamsted on fertile land, where large responses to nitrogen were not expected, the extent of lodging increased in both years with seed rate and with nitrogen, but it was more severe in the wet summer of 1954 than in the dry one of 1955. Total grain yield was 3 cwt./acre less from the 1 bu./acre seed rate than from 2 or 3 bu./acre in 1954, but in 1955 the differences were not significant; nitrogen did not significantly increase total grain yield either year. Yield of dressed grain was not affected by seed rate in 1954, but in 1955 it was reduced about 2 cwt./acre by each extra bushel of seed; nitrogen reduced the yield of dressed grain each year by about 3 cwt./acre for each extra 1½ cwt./acre of ammonium sulphate. The amount of weed seeds was reduced by increasing seed rate and increased by increasing nitrogen in 1954; in 1955 there were very few weeds. Nitrogen content of the grain in 1954 was not much affected by seed rate but was increased by extra nitrogen; it was highest in the smallest grain. S.F.A.

Nitrate fluctuations in tropical soils. D. J. Greenland, *J. agric. Sci.*, 1958, **50**, 82–92.

Determinations at fortnightly intervals on plots in various parts of Ghana showed that during the dry season the nitrifying power of the soil and the nitrifiable nitrogen (i.e. organic N converted to nitrate on incubation) increase on both cropped plots and carefully weeded fallow plots. Nitrification is slow during the dry season but rapid when the rains begin. Under bare fallow leaching was the most important cause of nitrate loss, but under annual crops denitrification probably contributed to the loss; there was no indication of microbial nitrate absorption. Under natural forest, levels of nitrate and nitrifiable nitrogen were high, probably representing an equilibrium level in a cycle where nitrogen fixation, nitrification and nitrate losses all proceed very rapidly. Natural savannah grassland suppresses nitrogen mineralization but organic nitrogen does not build up, partly owing to the low fixation rate, which in turn may be related to the low phosphorus level, and partly owing to losses of plant nitrogen as nitrogen dioxide during the annual burn of the vegetation. S.F.A.

Plant availability of various sources of phosphate rock. W. H. Armiger and M. Fried, *Proc. Soil Sci. Soc. Amer.*, 1957, **21**, 183–8.

Ten rock phosphates from different localities, viz. Tunis rock, Morocco rock, Curaçao, S. Carolina land rock, Florida land pebble and land pebble (flotation concentrate), Idaho phosphate rock, Tennessee brown phosphate rock, Montana rock and Virginia apatite, were compared in greenhouse tests as sources of phosphorus for lucerne and buckwheat on six different soil types. Tunisian rock gave the largest plant growth response and supplied more phosphorus than the other sources. Laboratory evaluation of the phosphate rocks using ammonium citrate and citric acid solubility tests correlated well with the growth tests and thus appear to give an efficient index for predicting their relative values. With the exception of the Curaçao rock, which had a high fluorine content, efficiency of the different rocks as sources of phosphorus appears to be correlated with carbonate content. E.M.A.

An evaluation of ten phosphorus sources by growth of four field crops. W. K. Robertson and C. E. Hutton, *Agron. J.*, 1958, **50**, 24–8.

Ten sources of phosphorus were compared in the field both with and without lime on fine sandy loam with maize, groundnuts, soya beans and oats as test crops. Rates of application of the fertilizers depended on their P content. Tables show the composition of the different fertilizers, crop responses over the six-year trial period, and the uptake of P from the different sources and their effects on soil *p*H and P content of the soil surface. The phosphorus sources are arranged in descending order of response as follows: superphosphate, dinitra phosphate (17–22–0), fused tricalcium phosphate (<40 mesh), dinitra phosphate (17–30–0), fused tricalcium phosphate (<10 mesh), concentrated superphosphate, calcium metaphosphate, potassium metaphosphate and rock phosphate. Basic slag was also included in the tests but applied at higher rates. The uptake of phosphorus from the different sources was also studied by means of P^{32}, and results indicate that the calcium, nitrogen and trace element content of the fertilizers also contribute to the efficiency of the fertilizers under test. E.M.A.

Calcium phosphate fertilizers: 1. Availability to plants and solubility in soils varying in pH. G. L. Terman, D. R. Bouldin and J. R. Mehr, *Proc. Soil Sci. Soc. Amer.*, 1958, **22**, 25–9.

The availability of phosphorus in six pure calcium phosphates, viz. monocalcium monohydrate (MCP), dicalcium dihydrate (DCPD), anhydrous dicalcium (DCPA), octocalcium (OCP), tricalcium (TCP) and hydroxyapatite (HAp), was determined using ryegrass and Sudan grass as test crops in three acid and two alkaline soils. Tables give the composition of the different phosphorus sources, the experimental soils, and yields of the two crops, while histograms illustrate the uptake of phosphorus by ryegrass from the different carriers. DCPD was more available than DCPA on all soils; on alkaline types MCP was more available than the dicalcium phosphates but less so on acid soils. On alkaline soils TCP had low availability but was as effective as DCPA in acid groups. HAp had low availability on all soil types. In soils of low phosphorus content placing the fertilizer 1½ in. below the surface markedly increased the availability, but in soils of high phosphorus content placement was without effect. A strong correlation existed between phosphorus extracted by 0·5 N $NaHCO_3$ and the phosphorus uptake by the two test crops. E.M.A.

The water-soluble carbohydrates of grasses. IV. The effect of different levels of fertilizer treatment. R. Waite, *J. Sci. Fd Agric.*, 1958, **9**, 39–43.

Established small plots of grasses received 0, 2 or 4 cwt./acre of NPK fertilizer (12 : 4 : 12) in late February and after each cut at the height of 8–10 in. In the absence of fertilizer the protein, fructosan, sucrose and hexose contents of the first cut as percentage of dry matter and the number of cuts respectively were: S23 ryegrass 6, 18, 2, 2, 1; S24 ryegrass 8, 23, 4, 3, 2; S53 meadow fescue 10, 13, 5, 3, 2; S48 timothy 8, 16, 4, 2, 2; S143 cocksfoot 12, 9, 2, 6, 3. As the amount of fertilizer was increased the number of cuts in the season rose, the crude protein content of the grass increased, and the soluble carbohydrate percentage, particularly fructosan, decreased for all species; the increase in protein was greatest in cocksfoot and least in ryegrass. Fructosan was the main soluble carbohydrate for all grasses in the absence of fertilizer, and for ryegrass all cuts after 2 cwt./acre fertilizer and the first three cuts after 4 cwt./acre fertilizer; sucrose was the main soluble carbohydrate for all cuts of cocksfoot, timothy and meadow fescue after 4 cwt./acre fertilizer and for cocksfoot after 2 cwt./acre fertilizer. S.F.A.

The composition and agricultural value of some grass species in Nigeria. V. A. Oyenuga, *Emp. J. exp. Agric.*, 1957, **25,** 237–55.

Chemical compositions of 20 pasture plants cut at 5 growth stages are tabulated. The plants were grown without fertilizers on soils recovered from bush fallow in south-western Nigeria. Differences due to growth stage outweighed any differences due to species. Crude fibre and soluble carbohydrates were directly related to maturity, whereas crude protein, true protein and silica-free ash were inversely related. S.F.A.

Visual symptoms of mineral deficiencies of *Hevea brasiliensis*. E. W. Bolle-Jones, *J. Rubb. Res. Inst. Malaya*, 1956, **14** (Comm. 300), 493–584.

Hevea brasiliensis seedlings of clones Tjir 1 and PB86 were grown in pot sand culture supplied with nutrient solutions of varying compositions to induce twelve different types of nutrient deficiencies, viz. those of N, P, K, S, Mg, Ca, Fe, Mn, B, Cu, Zn, and Mo. A short description of symptoms and effects of each deficiency is given and illustrated by photographs and coloured plates, while tables show the effects on clone growth and chemical composition. It is stated that many of these induced deficiencies, e.g. copper, have not been observed in the field, whereas others, such as magnesium, are of common occurrence. No attempt has been made in the paper to deal with the rectification of each deficiency under field conditions, an aspect which is to be covered by a future publication. E.M.A.

Gibberellic acid and the growth of crop plants. D. G. Morgan and G. C. Mees, *J. agric. Sci.*, 1958, **50,** 49–59.

Gibberellic acid sprayed on grassland (2 oz./acre at 100 gal./acre) stimulated the growth of all components of the swards, especially in spring and autumn, when the natural growth rate was slow. A single application reduced the yields of dry matter and crude protein at the second cut by approximately the amount of the increase at the first cut, but did not affect the botanical composition of the sward. Applications after each cut prevented the decreases in yield but led to a progressive thinning of the sward. Gibberellic acid and fertilizers acted quite independently in increasing dry matter and crude protein yields; when they were applied together their effects were additive. On winter wheat gibberellic acid at 2 and 4 oz./acre in spring stimulated growth for a time but did not increase grain or straw yields at harvest. Similar rates stimulated the vegetative growth of peas, runner beans, blackcurrants, potatoes, carrots, turnips and lettuce, but in no case was the crop yield increased. S.F.A.

CROP PROTECTION

Insektizide und akarizide Wirksamkeit von 2,4,5,4′-tetrachlor-diphenyl-sulphon (Tedion). (Insecticidal and acaricidal activity of 2,4,5,4′-tetrachloro-diphenyl-sulphone (Tedion).) J. Meltzer, *Z. angew. Ent.*, 1957, **41,** 58–63.

Dutch *in vitro* trials have established that Tedion is a highly specific acaricide, with no insecticidal action as a contact poison. *Musca domestica* and *Ephestia kuehniella* showed no symptoms of intoxication after contact for 2 days with films containing 1 mg. Tedion/70 cm^2. *Aphis* (*Doralis*) *fabae* and larvae of *Leptinotarsa decemlineata* and of *Diataraxia oleracea* were unharmed by feeding for 3–5 days on plants dipped in 0·1 % Tedion emulsion, and bees were unaffected by contact with Tedion at 16 g./m^2. In a further trial with bees, the insects were fed for 6 days with a honey-sugar paste containing up to 62,500 p.p.m. of Tedion: no significant kills were obtained, yet eggs of the red spider mite *Tetranychus urticae* could be killed by emulsions of digestive-tract extracts from the fed bees. Against red spider mites Tedion gave total kills of *T. urticae* at 3 p.p.m. (30 p.p.m. for eggs) and of *Metatetranychus ulmi* at 1 p.p.m. (100 p.p.m. for eggs). The mammalian toxicity of the acaricide is low, a dose of 5 g./kg. body weight being harmless to the rat. D.L.

The potato broad mite. G. H. S. Hooper, *Qd agric. J.*, 1957, **83,** 56–8.

The potato broad mite (*Hemitarsonemus latus*), which was of minor importance in Queensland before 1955, has recently become a serious pest. It exists on both spring and autumn potato crops, but only the autumn crop is damaged; it also infests many headland weeds. The mite causes some leaf curling, and the tubers from infested plants are severely split and malformed. The routine spraying of autumn potatoes with DDT is deprecated, for this is associated with the build-up of mite populations. Control has been achieved by using lime-sulphur 1 : 80, by spraying or dusting with sulphur, and by spraying dieldrin at a rate of ½ lb. active ingredient/acre as soon as there were signs of damage. D.L.

The influence of the apple spray programme on the incidence of the fruit tree red spider mite (*Metatetranychus ulmi* Koch) in Northern Ireland. R. J. Willis, *Res. exp. Rec. Minist. Agric. N. Ireland*, 1957, **5,** 12–28.

Orchard trials from 1952 to 1955 in Northern Ireland demonstrated that 0·05 % DDT sprayed on apple trees at the green-cluster stage induced a marked increase in populations of the fruit tree red spider mite. Comparable applications of 0·2 % BHC at green-cluster and pink-bud stages reduced mite populations, and kept them suppressed throughout the summer. BHC at the same rate sprayed at petal fall did not reduce mite numbers to the same degree as the pre-blossom sprays, and in late summer there was a general, but not excessive, rise in the numbers of mites in some years. When Bordeaux mixture was replaced by mercurials in the fungicide programme there were no demonstrable changes in mite populations, but when captan was used the number of mites increased, even if 0·2 % BHC was included in the programme. Applications of 0·025 % CPCBS or 0·02 % Chlorbenside in early June and again in mid-July controlled the mites. D.L.

Some aspects of a ryania-glyodin spray schedule in British Columbia apple orchards. I. Entomological, horticultural, and economic aspects. C. V. G. Morgan and N. H. Anderson, *Canad. J. Plant Sci.*, 1957, **37,** 423–33.

Four applications of 100 % ryania, each at 48 lb./acre, together with glyodin as a fungicide, controlled light infestations of codling moth (*Carpocapsa pomonella*) in British Columbian apple orchards to a degree comparable with that given by 4 sprays of 50% DDT at 12 lb./acre with lime-sulphur, ferbam or wettable sulphur. Heavy infestations were better controlled by DDT. The ryania-glyodin schedule also controlled American blight (*Eriosoma lanigerum*) and *Aphis pomi*. It had little effect on predacious mites; yet, with the exception of the rust mite *Vasates schlechtendali*, phytophagous mites were not generally troublesome. Fruits were, however, reduced in size. D.L.

An Eriophyid mite causing damage to chrysanthemums. J. D. R. Vernon, *Plant Pathology*, 1957, **6**, 111.

Russeting of the stems of glasshouse chrysanthemums, leading to premature leaf drop and poor bloom quality, has occurred since 1949 in Scotland and since 1954 in Cheshire. The causal mite was identified as an Eriophyid, *Epitrimerus alinae*. It was found to be widespread in the Midlands, and could become a serious pest. Spraying with chlorbenzilate gave little control, and the routine use of lime-sulphur as a fungicide did not prevent the build-up of mite populations. Metasystox sprayed at 12 oz./100 gal. water gave total kills within 5 days, when the infestation rate was between 30 and 130 mites/stemtop. D.L.

Effect of mitotic poisons on house fly oviposition. N. Mitlin, B. A. Butt, and T. J. Shortino, *Physiol. Zoöl.*, 1957, **30**, 133–6.

Little work has been done on the control of insects by the chemical inhibition of their fertility. In the present study, carried out by the Entomology Research Branch, U.S. Department of Agriculture, house flies (*Musca domestica*) were fed on five mitotic poisons dissolved in milk. Three of the compounds—aminopterin (4-aminopteryl glutamic acid) at 0·2 mg./ml.; a nitrogen mustard (methyl bis-(β-chloroethyl) amine hydrochloride) at 2 mg./ml.; and colchicine at 0·5 mg./ml.—prevented ovarian development and caused sterility in female flies. Ovarian growth was also inhibited by a 5% solution of sucrose, but podophyllotoxin at 0·8 mg./ml. caused no apparent effect. The fertility of male flies was not affected by any of the poisons. The inhibition produced by sucrose could be reversed by later feeding with a normal skimmed-milk diet, but the effects of aminopterin were irreversible. D.L.

Reduced oviposition in *Aedes aegypti* L. following tarsal exposure to a fluorocarbon. K. R. S. Ascher, *Experientia*, 1958, **14**, 8–9.

Work at the Istituto Superiore di Sanita, Rome, has indicated the possibility of a novel approach to the control of insects. Female mosquitoes (*Aedes aegypti*) were exposed to deposits of 1 g./m.^{2} of di-(*p*-chlorophenyl)-trifluoromethylcarbinol for periods of up to 40 min. and then allowed a blood meal. Such exposure had no adverse effects on the mosquitoes, but subsequent oviposition at about 30 eggs/female was half that of normal mosquitoes. Total inhibition of oviposition also occurred: after exposure to the fluorocarbon for 30 min. only 31% of females laid eggs, compared with 77% in controls. Trials with DDT-resistant strains of *Anopheles stephensi* and *A. atroparvus* did not yield significant results. The abbreviation O.I.T.C. (oviposition-inhibiting tarsal contact agent) is suggested for this type of control agent. Initial trials have shown that greater inhibition is given by di-(*p*-chlorophenyl)-pentafluoromethylcarbinol. D.L.

Insecticidal property of the fungus *Ganoderma lucidum* attacking palms. D. Seshagiri Rao, *Curr. Sci.*, 1957, **26**, 325–6.

Ganoderma lucidum causes a root disease of coconut palms. Extracts of the fruit body of the fungus in white kerosene oil were found in trials at Bangalore to be insecticidal. They were tested in spray formulations against the rice weevil (*Sitophilus oryzae*). An extract of 5·5% gave 92·5% kill at 24 hours. High kills were given by concentrations of 11–2·75%. D.L.

Studien über die biologische Bodenentseuchung. I. Einfluss der Bodenmikroflora auf *Ophiobolus graminis* Sacc. (Methodik). (Studies on the biological disinfection of the soil. I. Influence of the total soil microflora upon *O. graminis* Sacc. (Method).) H. Zogg, *Phytopath. Z.*, 1957, **30**, 315–26.

It has long been evident from field experience that foot rots of annual crops tend to be eliminated from the soil by the influence of the total soil microflora. In Switzerland the biological activity of the soil microflora was studied *in vitro* against the take-all fungus, *Ophiobolus graminis*. Unsterilized soil was added to established cultures of the organism in flasks. Wheat was sown in the flasks together with rape or clover as examples of normal undersowings, using surface-sterilized seed. Two to three weeks later the extent of the take-all on the wheat seedlings was assessed. There was good correlation between the experimental results and field experience; the total microflora of root-free soil from fields without susceptible crops in the rotation caused *O. graminis* to lose its pathogenicity within a few weeks; pathogenicity was partly maintained when the soil was used from fields with wheat in the rotation. The total microflora from fields under wheat for several years, and also from the rhizosphere of wheat, could not reduce the pathogenicity of *O. graminis*, but complete loss of pathogenicity was obtained by adding soil from rape or clover rhizospheres to the cultures. D.L.

Control of downy mildew of broccoli with antibiotics and fungicides. J. J. Natti, *Plant Dis. Reptr*, 1957, **41**, 780–9.

Germination of spores of the broccoli downy mildew fungus *Peronospora parasitica* was completely inhibited *in vitro* by the following antibiotics at concentrations of 12 p.p.m. or less: cycloheximide, ayfactin, candicidin, endomycin, filipin, fungichromin, neomycin sulphate, pleocidin, thiolutin, tricothecin, and tyrothricin. Anisomycin, polycycline, and streptomycin sulphate were equally effective at concentrations of 12–50 p.p.m., and mycostatin at 100 p.p.m. Amphotericin A and B, griseofulvin, oxytetracycline, and thiactin were ineffective. In greenhouse spray trials, anisomycin, mycostatin, streptomycin sulphate, and thiolutin gave the best control of the disease; streptomycin sulphate acted both topically and systemically, but caused some bleaching of the broccoli foliage. Out of nine fungicides tested in the greenhouse, maneb and chloranil formulations were outstanding. In field trials, Agri-Strep (37% streptomycin sulphate) at 3 lb./100 gal./acre reduced the average number of lesions/plant from 54·7 to 3·0, and to 2·6 when 1% glycerol was added. At this rate the foliage was bleached, and slight bleaching occurred when Agri-Strep was used at 0·6 lb./acre: at the latter rate the number of lesions was only reduced to 17·5/plant, but this was better than the degree of control afforded by maneb or chloranil. D.L.

The downward translocation of antibiotics in plants. R. A. Gray, *Phytopathology*, 1958, **48**, 71–8.

When streptothricin and pleocidin were sprayed on intermediate leaves of bean or tobacco at 1% concentration, the antibiotics were readily translocated downwards to older leaves and upwards to younger ones. Under the same conditions, streptomycin, dihydrostreptomycin, neomycin, oxamycin, bacitracin and actinomycin did not move out of the sprayed leaves in detectable amounts. Streptothricin at 0·1% was translocated to the roots and to young leaves when primary leaves of bean plants were immersed in the solution. Several of the antibiotics that failed to move out of sprayed leaves were translocated both upwards and downwards when a leaf was immersed in a solution of the antibiotic. Streptothricin and pleocidin, when applied by immersing a leaf in solutions of 0·2%, were translocated downwards through steam-killed sections of petioles and stems, indicating that such movement was mainly occurring in the xylem. Streptomycin amine and streptomycin oxime were found to be converted within the plant to compounds of higher antibacterial activity than the original antibiotics. D.L.

Inhibition of *Fusarium oxysporum* f. *lycopersici* by a species of *Micromonospora* isolated from tomato. G. E. Smith, *Phytopathology*, 1957, **47**, 429–32.

In a routine experiment with tomato plants it was found that *Fusarium oxysporum* f. *lycopersici* failed to induce the usual wilt symptoms or vascular discoloration in one plant out of fifteen that had been inoculated. Tissue cultures were made from this plant to ascertain whether the organism was present, and a species of *Micromonospora* was discovered. Plate tests with this organism on potato-dextrose agar showed that it inhibited the *Fusarium*; the latter would not grow on agar in which *Micromonospora* had grown for a day or longer. Similar inhibition was caused by a 50% concentration of a crude filtrate from *Micromonospora* broth cultures when added to the agar. The actinomycete caused no macroscopic symptoms in tomato. Symptoms of fusarium wilt were inhibited in tomato plants treated with *Micromonospora* cultures before soil or root inoculation with the pathogen. D.L.

Reversal of virus-caused stunting in plants by gibberellic acid. K. Maramarosch, *Science*, 1957. **126**, 651–2.

The use of gibberellic acid in overcoming genetic and physiological dwarfing has already been reported. The effect of the chemical on stunting caused by viruses was tested at the Rockefeller Institute for Medical Research, New York, using the corn stunt virus on sweet corn, aster yellows virus on *Callistephus*, and wound tumour virus on crimson clover. Severely stunted plants were sprayed 3 times at weekly intervals with a freshly prepared aqueous solution of gibberellic acid at 100 p.p.m. A week after the last application, the internodes of corn and *Callistephus* had elongated to twice their stunted length, and clover petioles had increased 3 times in length and become erect. In corn, the reversal of stunting became apparent 48 hours after the first application; it was visible in clover and *Callistephus* after 5 days. The plants retained other symptoms of virus infection, and leafhopper vectors recovered the viruses from plants treated with gibberellic acid as readily as from untreated controls. D.L.

Meristeemcultuur, gecombineerd met warmtebehandeling, voor het verkrijgen van virusvrije anjerplanten. (Meristem culture, combined with heat treatment, for the production of virus-free carnation plants.) F. Quak, *Tijdschr. PlZiekt.*, 1957, **63,** 13–14.

In attempts to produce virus-free plants of the carnation varieties Pink Sim and Harvest Moon in Holland, heat treatment was combined with that of culture from developing tissues. From plants that had been kept at 40° C for 4–6 weeks the meristem and some leaf primordia were isolated from stem tips and cultured in nutrient agar under sterile conditions. Small plants developed from these cultures and were transferred to soil; normal virus-free carnation plants resulted, and from these plants healthy stocks have been raised. D.L.

A new herbicide: 1,1′-ethylene-2,2′-dipyridylium dibromide. R. C. Brian, R. F. Homer, J. Stubbs, and R. L. Jones, *Nature, Lond.*, 1958, **181,** 446–7.

A new herbicide, 1,1′-ethylene-2,2′-dipyridylium dibromide, applied at 1–2 lb./acre, proved equal to sulphuric acid for potato haulm destruction and for pre-harvest desiccation of red clover seed crops in field trials. The following annual weeds were controlled by the new herbicide at 1 lb./acre or less: cleavers (*Galium aparine*), chickweed (*Stellaria media*), groundsel (*Senecio vulgaris*), mustard, speedwell (*Veronica* spp.), knotgrass (*Polygonum aviculare*), black bindweed (*P. convolvulus*), redshank (*P. persicaria*), charlock (*Sinapis arvensis*), runch (*Raphanus raphanistrum*), cut-leaved dead nettle (*Lamium hybridum*), many-seeded goosefoot (*Chenopodium polyspermum*), fat hen (*C. album*), orache (*Atriplex* spp.), scarlet pimpernel (*Anagallis arvensis*), mayweed (*Matricaria* spp.), and Russian thistle (*Salsola pestifer*); 1 lb./acre did not control corn poppy (*Papaver rhoeas*), corn marigold (*Chrysanthemum segetum*) or parsley piert (*Aphanes arvensis*). Good kill of the top growth of several broad-leaved perennial weeds and brushwood species were obtained, but the initial die-back was followed by basal regeneration. Damage to cereals increased in the order oats, wheat, maize, barley; on oats rates up to 2 lb./acre caused only localized foliar scorch, whereas spring barley yields were reduced by sprays at 1 lb./acre even at the 2–3 leaf stage. S.F.A.

The phytotoxicity of four phenyl urea herbicides in soil. T. J. Sheets and A. S. Crafts, *Weeds*, 1957, **5,** 93.

The substituted urea herbicides may persist in the soil for considerable periods after treatment, and are used extensively as pre-emergence and post-emergence herbicides and as soil sterilants. Greenhouse tests were carried out to investigate initial and residual toxicities of 3-(*p*-chlorophenyl)-1,1-dimethylurea (monuron), 3-(3,4-dichlorophenyl)-1,1-dimethylurea (diuron), 3-(3,4-dichlorophenyl)-1-methylurea (DMU) and 3-(phenyl)-1,1-dimethylurea (fenuron) in a Yolo clay loam. To investigate residual toxicity split plot tests were carried out in which each chemical was mixed with autoclaved and non-autoclaved soil at 0·0–8·0 p.p.m. by weight of air-dry soil. The soil, sown with Kanata oats, was either continuously cropped to give continuously moist soil or cropped alternate months to give dry soil every other month. The toxicity of all four chemicals decreased more rapidly in non-autoclaved soil and continuously moist soil than in initially autoclaved soil and soil kept dry alternate months. This suggests that the chemicals are broken down by micro-organisms in the soil, and that the conditions for this breakdown are least favourable under arid conditions. The order of toxicity in the autoclaved soil was the same throughout ten months of treatment; monuron was most toxic, then fenuron, diuron and DMU. In non-autoclaved soil fenuron was the least toxic after ten months, which suggests that its greater solubility and absence of a chlorine atom on its phenyl ring make it more readily inactivated microbiologically than the other three compounds. The initial soil toxicity was compared against the toxicity in a nutrient solution of concentration 0·001–3·125 p.p.m. by weight. All four chemicals were more toxic in nutrient solution than in the soil; diuron and DMU were most toxic in solution and initially monuron and fenuron most toxic in the soil, although the order of toxicity varies with different soils. The toxicity in nutrient solution is related to chlorine substitution in the phenyl ring, the substitution of two chlorines in diuron and DMU greatly enhancing their toxicity. The position is inversed initially in the soil probably because of fixation by soil colloids. Solubility is another factor to be taken into account, and more work must be done before the factors controlling toxicity can finally be evaluated. R.A.U.

Effect of certain herbicides on rate of nitrification and carbon dioxide evolution in soil. R. W. Teater, J. L. Mortensen and P. F. Pratt, *J. agric. Fd Chem.*, 1958, **6**, 214–16.

Two experiments were conducted to find the effect of α-chloro-N, N-diethylacetamide (CDEA), 2-chloroallyl diethyldithiocarbamate (CDEC), isopropyl-N-(3-chlorophenyl) carbamate (CIPC) applied at 6·24 and 96 lb./acre and the triethanolamine salt of 2,4-D at 2·8 and 32 lb./acre on nitrate accumulation and general microbiological activity as measured by carbon dioxide evolution in incubated soil. Used at rates comparable to recommended field application for weed control, viz. 2 lb./acre 2,4-D amine and 6 lb./acre for CDEA, CDEC and IPC, the herbicides had little effect on nitrate accumulation or carbon dioxide evolution. Higher rates inhibited nitrification but increased carbon dioxide evolution. It is suggested that these herbicides may exhibit a bacteriostatic effect on some organisms but allow others to multiply undisturbed. At very high rates all four weedkillers are probably bacteriostatic to all micro-organisms in soil. E.M.A.

The effects of several herbicides on nitrification in the field soil under laboratory conditions. M. G. Hale, F. H. Hulcher, and W. E. Chappell, *Weeds*, 1957, **5**, 331–41.

Percolation and manometric methods were used to study the effect of sodium 2,4-dichlorophenoxyethyl sulphate (2,4-DES), isopropyl N-(3-chlorophenyl)-carbamate (CIPC), alkanolamine salts of 4,6-dinitro-ortho-secondary butyl phenol (DNBP), 2,2-dichloropropionic acid (dalapon), 2-(2,4,5-trichlorophenoxy)-propionic acid (2,4,5-TP), 3-(p-chlorophenyl)-1, 1-dimethyl urea (CMU), and sodium pentachlorophenate (PCP) on the rate of biological oxidation of the ammonium ion in the soil. In percolation studies on fresh field soil it was shown that 80 p.p.m. CIPC completely inhibited growth of micro-organisms, but up to 40 p.p.m. CMU was ineffective. In soils in which a constant rate of nitrification had been reached nitrification was inhibited 90% by 160 p.p.m. CIPC and 50% by 40 p.p.m. CMU. Using the seven named chemicals in manometric studies it was shown that PCP, DNBP, CIPC, and CMU were most inhibitory with regard to oxygen uptake of soil, the inhibition of respiration being greatest with PCP. It was shown, however, that the concentrations of herbicides which inhibited respiration by 50% would not occur at usual field application rates and that there would be little or no detrimental effects on nitrification. E.M.A.

Effects of annual grass weeds on the yield of corn. D. W. Staniforth, *Agron. J.*, 1957, **49**, 551–5.

Results are given of a split-plot randomized block experiment with four replicates, three levels of nitrogen application and two levels of maize population. Yellow foxtail was removed at different stages of maize growth to estimate the period of severest competition. Yields of maize were greatest when the weed was removed at early stages of crop growth, yield reductions resulting from mature foxtail infestations averaged 14, 10 and 5 bu./acre respectively with applications of 0, 70 and 140 lb. N/acre. Maize yields were increased 2–3 times more than foxtail by the fertilizer applications. It appears also that competition between maize and weed is greatest with lower plant populations. E.M.A.

Competition between skeleton weed (*Chondrilla juncea* L.) and cereals in relation to nitrogen supply. L. F. Myers and J. Lipsett, *Aust. J. agri. Res.*, 1958, **9**, 1–12.

This investigation on competition between skeleton weed and wheat and oats, carried out in seasons of plentiful rainfall, showed nitrogen to be a major factor in limiting crop yields. Density of skeleton weed determined the crops' response to nitrogen and was severest at low nitrogen levels and least after heavy nitrogen application or in cereals grown after legume-rich pasture. The weed was removed by MCPA spray at different stages of growth to determine at which point of development of cereals competition was critical. Competition was greatest at early stages of cereal growth. Equal increases in yield were obtained with oats grown after fallow from either 1 lb. MCPA/acre applied 54 days before sowing or 10 days after crop emergence and 32 lb. N/acre applied at planting. Times of application of both weedkiller and N fertilizer produced similar effects: applied early each increased yield, applied late they increased N content of the grain. E.M.A.

Factors affecting dormancy and seedling development in wild oats. T. Kommedahl, J. E. DeVay, and C. M. Christensen, *Weeds*, 1958, **6**, 12–18.

Investigations were carried out on wild oats to determine the effect of hull colour, dehulling grain, hull extracts, wetting and drying, size and microflora of grain on dormancy. Hull colour was not correlated with percentage germination, but large grain germinated 20% more than the small. Regardless of hull colour, dehulling caused increased germination while soaking grain in water under partial pressure reduced it. Alternate wetting and drying grain also reduced percentage germination considerably, but only when the hull was attached. A water extract of hulls reduced germination rate. Yeast colonies were found to be 10–50 times greater in non-germinated grains. It was not established, however, whether dormancy could be attributed to substances produced in the hull or the microflora or toxic substances produced by them within the hull. E.M.A.

Control of annual bluegrass and crabgrass in turf with fluorophenoxyacetic acids. B. R. Anderson and S. R. McLane, *Weeds*, 1958, **6**, 52–8.

In primary screening tests induction of sterility appeared to be an important effect of certain fluorophenoxyacetic acids, and subsequent experiments using nine derivatives showed 4-fluorophenoxyacetic to be outstanding in its effect on the panicle. In greenhouse trials on millet this chemical applied at 1 lb./acre reduced seed production by 80–100%. Degree of susceptibility of millet was dependent on growth stage, but seed yield was reduced by 70% by application of 0·25 lb./acre at the most susceptible stage. Induction of sterility was not so complete in field tests. In greenhouse trials on annual bluegrass 0·5 lb./acre 4-fluorophenoxyacetic acid caused sterility for periods of 4–6 weeks after treatment, while in the field plants failed to produce seed-heads 5 weeks after treatment with 0·5–1·0 lb./acre. Crabgrass grown in pots was severely checked by 0·5 lb./acre and produced malformed sterile heads but recovered after 6–8 weeks and sent out normal tillers. On Kentucky bluegrass and bentgrass 1 lb./acre applied in the field appeared without effect. It is suggested that 4-fluorophenoxyacetic acid is a promising chemical for control of annual bluegrass and crabgrass in fine turf by destruction of the seed crop. E.M.A.

Damage to crops by birds and mammals, and methods for the prevention of such damage. E. van Koersveld, *Meded. Inst. Toegep. biol. Onderz. Nat.*, 1957, No. 32, 9–71.

Contributed as the main basis for discussion at an international conference on wildlife repellents, Arnhem, October 1955, this paper brings together an invaluable amount of information on the pest status of vertebrates in European agriculture and forestry. As an increasing area of land is brought into use by man, so do the problems posed by wild animals gain in importance. Assessment of the damage done is no easy task, for "species harmful in one way may be beneficial in another, in which case the most desirable situation would be prevention of damage, for example by repellents, while the population density is maintained at a level at which the beneficial effect is maximal." At present three lines of approach to damage assessment are made: field observations, analysis of stomach or crop contents, and caged field experiments. This last method is proving of considerable interest in the Netherlands, where it has been used for wild geese and is being tried with woodpigeons, coots, roe deer and hares. Indications of the types of damage done are exhaustively tabulated in 28 pages. Figures of total damage can be misleading, but it has been estimated that starlings alone are responsible for damage in the Netherlands valued at 2–3 million guilders. The first line of defence is placed on methods of husbandry and crop selection, and thereafter the use of repellents is advocated. The relative merits of different types of repellents are critically reviewed, as also are chemical and physical methods for destroying birds and mammals. Emphasis is placed on the need for selective action, so that beneficial species may be spared: the value of the gun is therefore high, and British figures of kills compared with the number of cartridges used show that the method is not so wasteful as has sometimes been thought. The great majority of poisons are not selective, and narcotics are thus potentially more suitable. Thirteen pages are devoted to control measures that have been found effective against individual pests. In conclusion, the need is stressed for fuller research on many aspects of the general problem, such as damage assessment, the development of chemical repellents, and ecological studies of the major pest species.

D.L.

Insecticiden of biologische maatregelen tegen de veldmuis, *Microtus arvalis* (Pallas), in de fruitteelt. (Insecticides or biological measures in the control of the continental vole, *Microtus arvalis* (Pallas), in orchards.) A. van Wijngaarden, *Meded. Dir. Tuinb.*, 1957, **20**, 369–74.

In the Netherlands the continental vole is a major pest of orchards bordering pastures, especially in years when the population density reaches its natural peaks. Three types of control were considered in 1955. Poison baits, such as wheat treated with zinc phosphide or pyrimidine, were effective but difficult to apply with the available labour. Good control was given by spraying insecticides: endrin, 1–1·7 kg. of 30% emulsion in 400–600 l./ha.; or toxaphene, 4–6 kg. of 50% emulsion at the same application rate. The use of this method on a large scale was considered too hazardous to man, cattle and game. There were indications that biological control might prove practicable, for the voles were unable to infest meadows that were regularly mowed or grazed, even when the fields were surrounded by areas of high infestation rate.

D.L.

ANIMAL HUSBANDRY

Experiments on the nutrition of the dairy heifer. 1. Protein requirements of yearling stock. G. L. Bailey and W. H. Brester, *J. agric. Sci.*, 1957, **49**, 435–45.

The response to increments of protein in the ration was found to be curvilinear, with a rapid decline in response above a critical intake level which varied with the liveweight of the animal, being 0·8 lb. crude protein at 300 lb. liveweight and 1·0 lb. at 400 and 500 lb. when rations were based on hay, decorticated groundnut meal and flaked maize. No marked difference was observed between the values of decorticated groundnut meal and white fish meal as protein supplements; urea was inferior to decorticated groundnut meal.

S.F.A.

The value of rumen inoculations and of diets containing sweetening agents for calves weaned on to dry food at three weeks of age. T. R. Preston, *Proc. Brit. Soc. Anim. Prod.*, 1958, 33–8.

Washed suspensions of ciliate protozoa, obtained from an adult sheep, were introduced into the rumen of calves by a stomach tube; the inoculations had no effect on mean daily increases in liveweight or height at withers. Addition of 15% molassine meal to the basal diet of flaked maize, oats, groundnut meal and skimmed milk powder increased meal consumption during the period 2–8 weeks old and resulted in higher growth rates. Date meal had a rather smaller effect.

S.F.A.

Experiments in the oral administration of oestrogens to fattening beef stock. A. A. Bindloss, *Proc. Brit. Soc. Anim. Prod.*, 1958, 39–52.

Various levels of stilboestrol and hexoestrol were added to various diets. Responses in steers were consistent within treatments, and increased rate of liveweight gain varied from 21% in one trial to 52% in another; minor side-effects were noted, but these did not adversely affect the carcass grading. Response in rate of gain in heifers was variable and ranged from 0 to 33%. For maximum response the animals must receive an adequate protein intake.

S.F.A.

The growth of lambs at pasture. 1. A comparison of growth on long and short ryegrass swards. R. V. Large and C. R. W. Spedding, *J. Brit. Grassl. Soc.*, 1957, **12**, 235–40.

A perennial ryegrass sward in its second harvest year was divided into six plots: (1)–(3) were kept short by gang-mowing, periodic introduction of extraneous stock to remove excess herbage, and double stocking rate respectively; plots (4)–(6) were maintained long. Owing to the very dry spring there was no difference in sward height until the middle of June; from then the herbage on the "long" plots rapidly grew away from the stock, and large numbers of flowering heads appeared about the middle of July; with heavy rainfall in August, growth continued and the proportion of leaf in the "long" plots increased. There was no difference in growth rate between lambs on plots (1), (2) and (4)–(6) up to the end of July, by which time the lambs had reached a liveweight of 90 lb. or over; lambs on plot (3) grew more slowly, and by the end of July the mean liveweight was below 70 lb. During August and September the liveweights of lambs on plots (1) and (4)–(6) levelled out at about 100 and 94 lb. respectively. After 8th August the lambs on plots (2) and (3) rapidly lost weight owing to heavy worm infestation, and they were removed from the experiment on 3rd September, when one lamb on plot (2) was found dead.

S.F.A.

The clinician's approach to mastitis. J. B. White, *Vet. Rec.*, 1958, **70**, 185–7.

This paper reviews developments in the clinical approach to mastitis during the last 25 years. The change from purely symptomatic treatment to the use of acridine dyes, the sulphonamides and antibiotics has "changed the pattern," and there has been a marked increase in staphylococcal mastitis. Many other organisms which were never regarded as pathogens a few years ago now cause mastitis. Some farmers keep their herds virtually free without antibiotics or disinfectants, while others consistently fail to do so. Although some types of mastitis can be recognized clinically with reasonable accuracy, the greatest difficulty for the clinician is classification of type at first visit so that the most suitable antibiotic can be adopted in each case. There has thus been a great demand for broad-spectrum antibiotics, which are very useful but expensive. Neither are they effective in all cases. Whatever treatment is applied, it is sound to give full doses and continue them for at least 3 or 4 days. If a treatment is not effective within 48 hours, it should be changed. Great stress is laid on prevention by correct milking machine technique and good husbandry. F.W.W.

Factors that predispose to mastitis, with special reference to milking technique. C. D. Wilson, *Vet. Rec.*, 1958, **70,** 159–66.

It is emphasized that mastitis is not merely a question of an infectious agent gaining access to a susceptible host. Infection will only proceed to invasion, especially with the less-adapted parasites, when some external factor has lowered resistance. Although housing, feeding, and general management have been suggested as playing a part, the most common factor influencing mastitis is milking technique. This is discussed in detail, and the basic principles of the milking machine and the characteristics of its components and accessories are described. It is concluded that the main part of the machine concerned in mastitis causation is liner design, with special reference to the bore, tension, and softness of the mouthpiece. Pulsation rate and height of vacuum are doubtful factors, but inadequate vacuum reserve with consequent surging has been implicated in a number of cases. The most important consideration in all cases of a specific mastitis is the adoption of a satisfactory milking technique which ensures that every cow has the cluster removed as soon as she has finished milking, without excessive stripping. Cowmen should be instructed how to use their present equipment properly, and when this is mastered it will be time to introduce innovations to further increase speed of milking. (*From author's summary.*)

Mastitis caused by bacterial infection. S. J. Edwards, *Vet. Rec.*, 1958, **70,** 139–41.

The incidence of clinical mastitis is not thought to have been reduced by the use of antibiotics. Recent surveys indicate that approximately 10% of cows per annum show clinical symptoms, and the opinion is expressed that if sub-clinical cases were included this figure might be doubled. Many herds have been freed of infection by *Strept. agalactiae*, and interest now centres around the organisms causing mastitis in such herds, about which there is little published information. It is stated that the "infection rate" for staphylococci may now be as high as 50–60% both in Britain and in America, compared with a clinical incidence of 8–10%. Infection rate rises with age, and staphylococcal mastitis is commonest in the first week after calving. Among streptococci, both *Strept. uberis* and *Strept. dysgalactiae* have assumed greater importance since the reduction in recent years of *Strept. agalactiae* infection by the widespread use of penicillin. It is common practice at present to use penicillin for general treatment, but it would be an advantage to check the identity of the common causal organism in a herd and to verify that it is sensitive to this antibiotic or to any other. Incidence of *C. pyogenes*, the common cause of summer mastitis, which is normally low, may greatly increase in certain years, e.g. 1954. There is now support from experimental evidence of its transmission by flies. For prevention two doses of procaine penicillin in oil at three weeks' interval into the teats of dry cows during the summer are recommended. The importance of examining the udders of dry cows daily is stressed. F.W.W.

The application of magnesium compounds to pasture for the control of hypomagnesaemia in grazing cattle: a comparison between magnesian limestone and calcined magnesite. W. H. Parr and R. Allcroft, *Vet. Rec.*, 1957, **69,** 1041–7.

Pasture was heavily manured with ammonium sulphate in an attempt to produce hypomagnesaemia in grazing cows. The effect of 2½ tons of magnesian limestone per acre in preventing hypomagnesaemia in cows grazing such pasture was compared with that of 10 cwt. of calcined magnesite per acre, which supplied the same amount of magnesium. The calcined magnesite was more effective in raising the pasture magnesium content and in preventing hypomagnesaemia. It increased the pasture magnesium content by an average of 73%, compared with 23% for the pasture manured with magnesian limestone. These results suggest that calcium may influence the uptake of magnesium by pasture. The magnesium content of the pasture showed a seasonal trend and that of pasture treated with the calcined magnesite also appeared to vary according to the stage of growth. The results confirm that the use of magnesium manures has a beneficial effect on pasture composition and cattle blood-magnesium levels. They clearly indicate, however, the superiority of calcined magnesite. The difference between the two manures suggests that the simultaneous application of calcium antagonizes the uptake of magnesium by pasture. (*From authors' summary.*)

The use of fine-particle phenothiazine against *Trichostrongylus colubriformis* in sheep with observations on its use against other species of worms. P. L. Thomas and D. C. Elliott, *N.Z. Vet. J.*, 1957, **5,** 66–9.

Experimental lots of phenothiazine of nominal particle size 1, 4 and 10 microns were tested against worm parasites of sheep, all being given in a single dose of 20 g. to groups of 15 sheep. Together with untreated control animals all the sheep were killed for examination either 10 or 12 days after dosing. Against *Trichostrongylus colubriformis* phenothiazine of 4 μ particle size was superior to phenothiazine of 10 μ size, but the effect was neither increased nor reduced with the finest material investigated. Indications were also obtained that against *Haemonchus contortus* and *Cooperia* spp. 4 μ particles may be optimum. Against *T. axei* the finest particles were probably best. Against *Ostertagia* spp. the finest preparation used was the only one to give a highly significant reduction compared with the controls. Against the large bowel worms *Oesophagostomum* spp. and *Chabertia ovina* there was evidence of a falling off in activity when particle sizes were reduced beyond 10 μ. It is suggested that the ideal phenothiazine preparation, both for anthelmintic and manufacturing considerations, is one which contains 70% of particles under 5 μ or 90% under 10 μ, with the remainder of the particles up to 30 μ. J.T.E.

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